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Municipal/Industrial Strategy for Abatement

KAMINISTIQUIA RIVER

WATER QUALITY STUDY

PART 1: WASTE ASSIMILATION CAPACITY

APRIL 1988

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KAMINISTIQUIA RIVER
WATER QUALITY STUDY
PART 1: WASTE ASSIMILATION CAPACITY

S.R. KLOSE
RIVER SYSTEMS SECTION
MINISTRY OF THE ENVIRONMENT

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The nature and complexity of the lower Kaministiquia River necessitated a rather complex and ambitious field program. The success of the field program can be attributed to the high level of cooperation between the Northwest Region and the River Systems Section, both of MOE.
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FOREWORD

At the request of the Northwestern Region, the River Systems Section of the Water Resources Branch was asked to re-evaluate the waste assimilative capacity of the lower Kaministiquia River. The lower river was examined as part of a Regional Water Quality Survey of the Thunder Bay area in 1970.

The study of the Kaministiquia River, originally planned in 1985, was subsequently expanded and included as a Municipal Industrial Strategy for Abatement (MISA) pilot site. Inclusion of the MISA objectives for the site study expanded the range of investigation from traditional nutrient and oxygen consuming waste concerns to include all known and suspected contaminants from point source dischargers to the river.

This report presents the findings of water quality surveys carried out in 1986 as they relate to the assimilative capacity of the lower river. The findings focus on the impact of oxygen consuming wastes. Results and analyses covering the MISA objectives will follow in subsequent technical reports leading up to a final pilot site synthesis report.

In addition to the MISA study activities the entire Thunder Bay nearshore area is under investigation as part of the Remedial Action Plan (RAP) process.

SUMMARY

The River Systems Section of the Water Resources Branch in cooperation with the Northwestern Region planned and carried out water quality surveys of the lower Kaministiquia River in 1986. The objectives of the study were to re-evaluate the waste assimilative capacity of the river and to satisfy the broader goals of the Municipal-Industrial Strategy for Abatement (MISA) pilot site program. This report presents the results for the waste assimilation study.

In the lower Kaministiquia River, warmer oxygen depleted river water was found to overlie colder oxygen saturated lake water. Lake water intruded up to the Westfort Turning Basin as was found in 1970. Mean dissolved oxygen levels in the upper layer river water reached minimums of 3 mg/l with extreme discrete measurements as low as 0.2 mg/l. Total Phosphorus was found to exceed the Provincial Water Quality Guideline as well.

The Great Lakes Forest Products Company was found to be the most significant contributor of oxygen consuming wastes. In order to attain an objective of 5 mg/l dissolved oxygen at design flow conditions, Great Lakes would have to reduce their discharge of oxygen consuming wastes by 75%.

An analysis of the impact of toxic contaminants (organic and inorganic) will be forthcoming as the MISA pilot site program advances.

SOMMAIRE

La Section des réseaux fluviaux de la Direction des ressources en eau, de concert avec la Région du Nord-Ouest, a planifié et effectué des contrôles de la qualité de l'eau de la basse Kaministiquia en 1986. L'étude avait pour buts de réévaluer la capacité de la rivière d'assimiler les eaux usées, et d'atteindre les grands objectifs du programme pilote relevant de la Stratégie municipale et industrielle de dépollution (SMID).

On a constaté que dans la basse Kaministiquia, un courant d'eau de rivière chaude désoxygénée se superpose à un courant d'eau de lac froide saturée d'oxygène. L'eau du lac se rendrait jusqu'au bassin de manoeuvre de Westford, comme on l'a observé en 1970. La concentration moyenne d'oxygène dissous atteindrait un minimum de 3 mg/L dans la couche supérieure de l'eau de la rivière; on a cependant relevé des concentrations de seulement 0,2 mg/L. En outre, les quantités de phosphore total dépasseraient les valeurs prévues dans les lignes directrices provinciales sur la qualité de l'eau.

La Great Lakes Forest Products Company constitue la principale source d'eaux usées causant la désoxygénation. Afin d'atteindre un objectif de 5 mg/L d'oxygène dissous en situation de débit nominal, la compagnie devra réduire de 75 % ses déversements d'eaux usées causant la désoxygénation.

Les effets des polluants toxiques (organiques et inorganiques) seront analysés dans le courant du programme pilote de la SMID.

1. INTRODUCTION

1.1 Background

In 1970, the Ontario Ministry of the Environment (MOE) conducted water quality investigations in the lower Kaministiquia River and Thunder Bay Harbour areas (MOE, 1972). The study was undertaken to evaluate the degree and extent of water quality impairment. The lower Kaministiquia River was the most seriously affected area in the study region, particularly in terms of nutrients, excessive loadings of oxygen-consuming wastes (BOD), suspended solids, accumulation of organic materials and metals in bottom deposits, bacterial contamination, aesthetic impairment and potentially toxic and tainting substances. Dissolved oxygen levels at the time of the study were well below 5 mg/L which is considered to be the concentration necessary for the protection of cold water fisheries and other desirable forms of aquatic life. The bacterial levels found suggested that accepted criteria for swimming and bathing were exceeded. The appearance of the river was severely degraded by suspended materials, scum, coloured substances, and floating oil wastes which imposed further restrictions on water-based recreational activities.

Pollution abatement programs carried out by the City of Thunder Bay and the major industries in the area, following the 1970 survey, have significantly improved the water quality. Concerns over impaired dissolved oxygen levels remain. In 1986, the MOE again carried out a water quality investigation of the lower Kaministiquia River to:

(1) re-evaluate the waste assimilation capacity, and:

(2) develop water-quality based techniques for setting effluent

limits as part of the Municipal-Industrial Strategy for Abatement program.

1.2 Study Area

The Kaministiquia River rises in Dog Lake, situated about 40 km northwest of Thunder Bay, and drains an area of approximately 6800 sq.km. The Shebandowan Lakes also feed the river via the Shebandowan River. Discharges from these lakes are regulated by control dams to facilitate hydro-electric power generation. Ontario Hydro regulates flow through control and operation of the Silver Falls Dam and Generating Station, the Shebandowan Lake Dam and the Kakabeka Falls Dam and Generating Station. Ontario Hydro maintains a minimum flow of 17 m^3/s at Kakabeka Falls Dam and Generating Station during the summer months.

The study area, as shown in Figure 1.1, covers the lower 10 km of the Kaministiquia River, as well as the Mission and McKellar Rivers which branch off of the Kaministiquia approximately 2 km upstream of Thunder Bay Harbour. The Kaministiquia River from the Westfort turning basin to the mouth, and the Mission River, have been dredged by the Canada Department of Public Works to a nominal depth of 7.6 m for commercial shipping. The McKellar River is not dredged. A very low gradient as well as the dredging allow a significant backwater effect of Lake Superior such that this section of the river behaves similar to an estuary.

1.3 Point Source Dischargers

As shown in Figure 1.1, there are 4 major point source dischargers to the lower Kaministiquia River. They are: The Great Lakes Forest Products Company, Reichhold Chemical, Ogilvie Mills Limited and the Thunder Bay Sewage Treatment Plant. The Ontario Hydro Thermal Generating Station and the Abitibi Paper Company Limited (Fort William Division) discharge directly into Thunder Bay harbour.

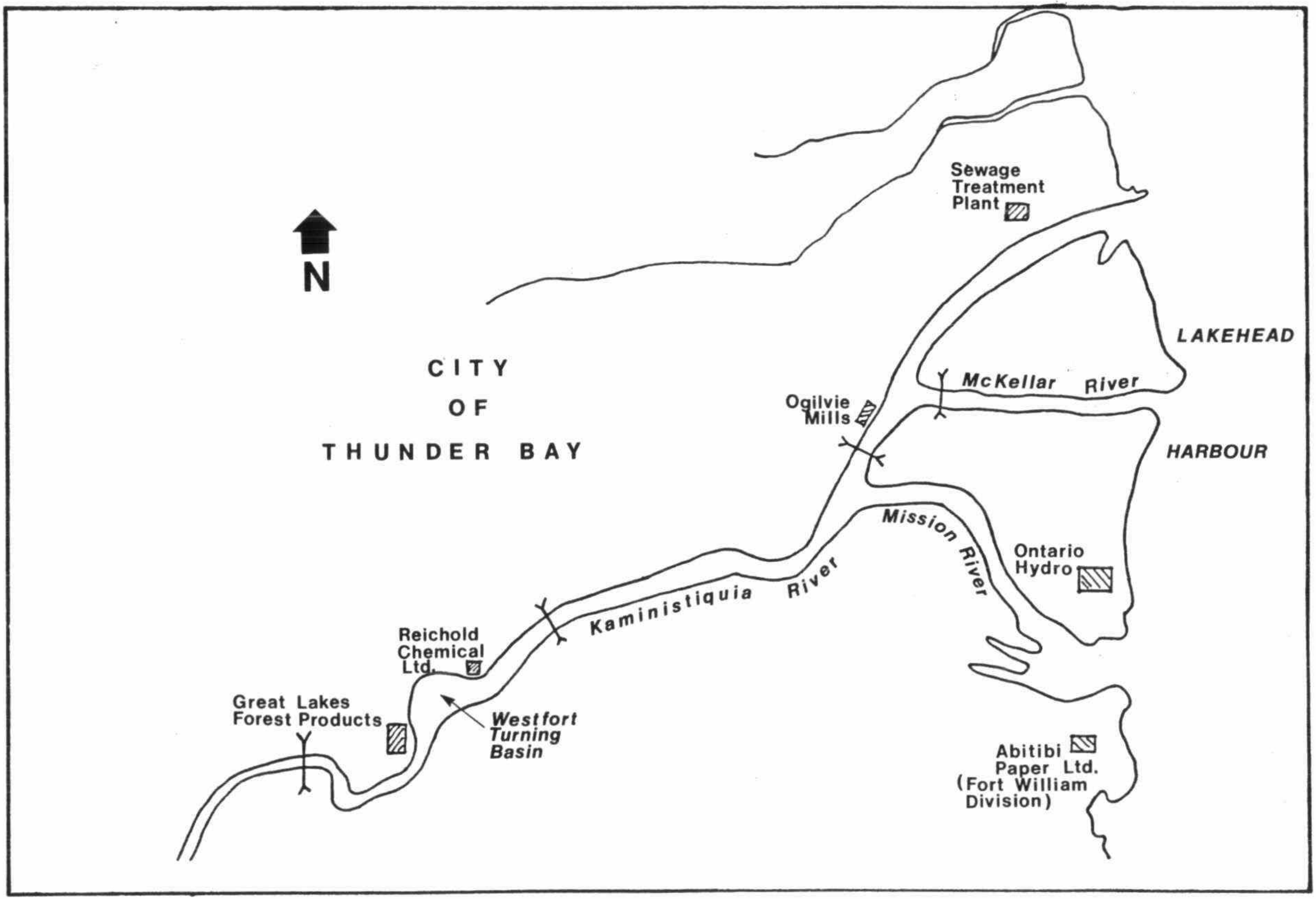


FIGURE 1.1: Lower Kaministiquia River Study Area.

The Great Lakes Forest Products Company operates a pulp and paper mill with facilities to produce newsprint from groundwood and sulphite pulp, and bleached and unbleached kraft pulp. Process water is withdrawn from the Kaministiquia River upstream of the mill and is discharged to the river via a submerged diffuser. A second outflow, "clean water discharge", from the plant is located at the head of the Westfort turning basin.

The Reichhold Chemical plant produces formaldehyde for use in making urea formaldehyde resin and phenol formaldehyde resin which are sold as adhesives for plywood and other wood products. The company is currently seeking approval to allow it to discharge to the sanitary sewer system thus removing it as a point source discharger. Ogilvie Mills Limited produces wheat gluten and starch. Process wastewaters are discharged via a bank outfall.

The Thunder Bay sewage treatment plant is a primary treatment plant with phosphorus removal with a capacity of 24 MIGD. Effluent chlorination is practised on a year-round basis. Less emphasis for river dissolved oxygen levels is placed on the treatment plant discharge, as compared to the other dischargers, due to its' nearness to the end of the study reach.

1.4 Survey Procedures

Intensive studies of the lower Kamistiquia River as well as the input from point source dischargers were conducted from July 29 to August 1, 1986 and August 11 to August 15, 1986. Figure 1.2 shows the river station locations and the point source discharge stations. Field measurements of water quality were collected on a 4 hour time step, along with samples for laboratory analysis on an 8 hour time step, during a 72-hour period. Table 1.1 summarizes the data collection schedule.

The survey design and data collection procedures were derived from

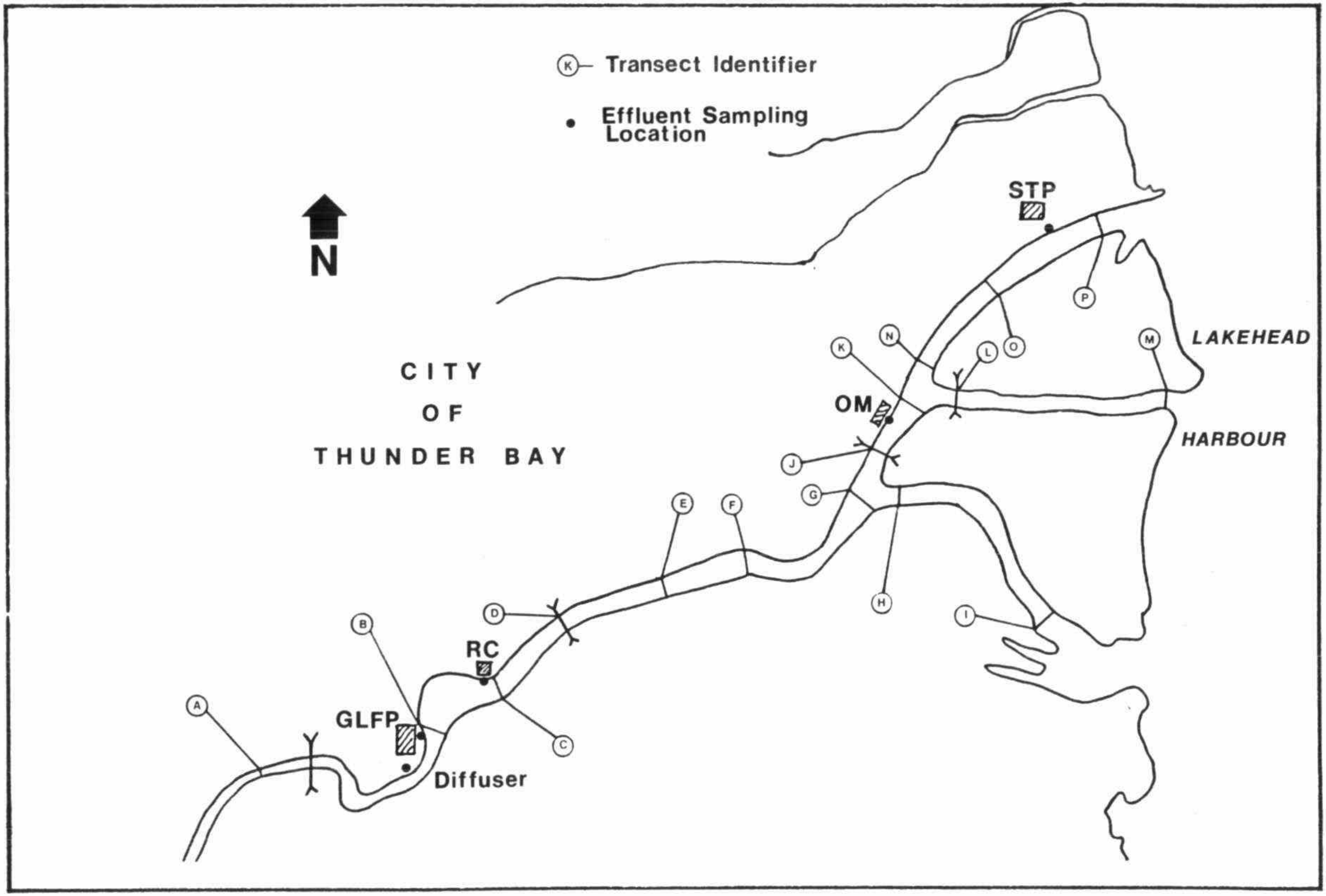


FIGURE 1.2: River Sampling Locations.

TABLE 1.1

72 - HOUR INTENSIVE SURVEY DATA COLLECTION SUMMARY

STATION	FIELD DATA * (4 hr. time-step)	WATER QUALITY ** (8 Hr. time-step)
A	+	+
B***	+	+
C	+	+
D	+	+
E	+	
F	+	+
G	+	+
J	+	+
K***	+	+
N	+	
O	+	+
P***	+	+
H	+	+
I	+	+
L	+	+
M	+	+
Point Source Discharges	+	+

* temperature, conductivity, pH, dissolved oxygen

** BOD_5, solids, COD, conductivity, true colour, turbidity, alkalinity, sodium, nitrogen, phosphorus, pH, chloride, sulphate, calcium, magnesium.

*** three samples were collected equally spaced across the river to identify the presence or absence of a mixing zone.

the Stream Water Quality Assessment Procedures Manual (MOE, 1980). One notable exception to the procedures outlined in the manual was that measurements of time-of-travel and the 72-hour intensive sampling were conducted at design flow conditions. Normally these measurements are made under dry weather summer conditions. The results and analyses are then extrapolated to design flow conditions. Significant backwater effects make it extremely difficult to extrapolate to design flow conditions with any degree of confidence. Arrangements were made with Ontario Hydro to regulate the Kaministiquia River such that design flow conditions would occur. A benefit to this modified procedure is that analyses and modelling can be performed on the data as collected without extrapolation.

2. FINDINGS

2.1 Physical Data

Table 2.1 summarizes reach lengths and metered cross-sectional areas. Figure 2.1 shows several typical cross-sections, and a plot of the bottom elevation of the river. From the summary (table 2.1) it can be seen that cross-sectional area increases significantly beyond Station A, which is as expected due to dredging. Also of note is the slight constriction of the channel at Station J due to bridge abutments.

2.2 Velocity/Flow Measurements

Within the Kamistiquia River watershed, the Water Survey of Canada operates 6 continuous streamflow recording stations (see Figure 2.2). Of these, three have records dating back prior to 1960.

The first streamflow station upstream of the study area is located at the Kakabeka Falls Powerhouse and is also the control point at which Ontario Hydro is attempting to maintain a minimum flow of 17 m^3/s. This station has been in operation since 1923, however, daily streamflow discharges have only been published since 1975. The next station upstream is located at Kaministiquia and has records dating back to 1926. Data from this station were used to perform a low flow frequency analysis.

Figure 2.3 shows the average recurrence interval for streamflow in the Kaministiquia River at Kaministiquia, utilizing data from 1971-1985. Records prior to 1971 were not used as the agreement with Hydro was initiated in 1971. Also, it is felt that data from the Kaministiquia gauge will reflect that from the Kakabeka Falls

TABLE 2.1 PHYSICAL DATA

STATION	DISTANCE(m)		WIDTH(m^2)	AVERAGE DEPTH (m)	CROSS-SECTIONAL AREA (m^2)
	INCREMENTAL	CUMULATIVE			
A	0	0	102	3.98	406
B	1425	1425			
C	1000	2425	165	7.33	1210
D	850	3275			
E	840	4115	173	7.40	1280
F	620	4735	150	7.13	1070
G	1210	5945	120	8.17	980
J	950	6895	80	7.81	625
K	570	7465			
N	475	7940	150	7.33	1100
O	875	8815			
P	1130	9945			
H	1300	7245	173	7.11	1230
I	1400	8645			
L	375	7840	90	6.22	560
M	1900	9740			

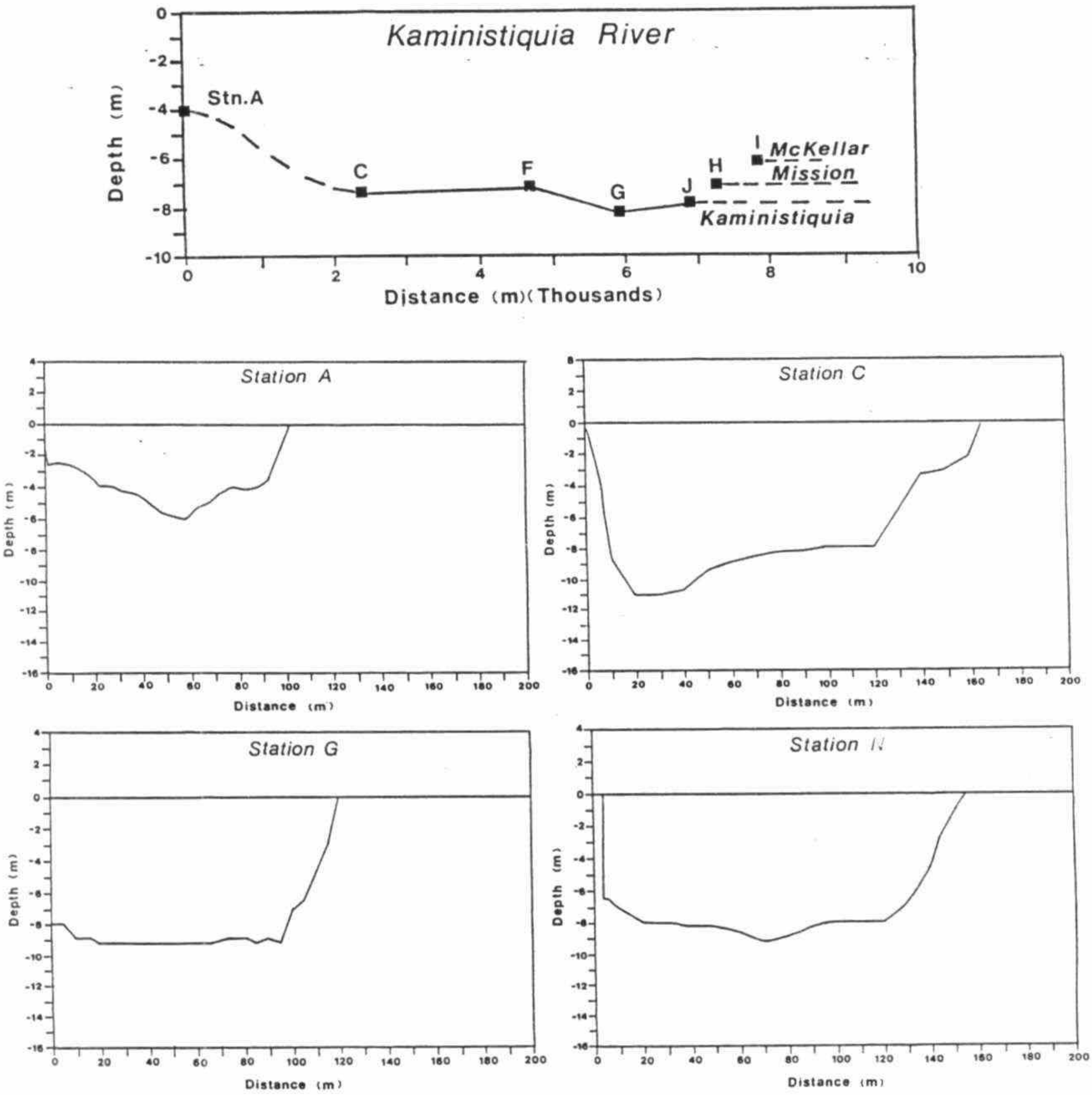


FIGURE 2.1: Kam River Profile and Cross-sections.

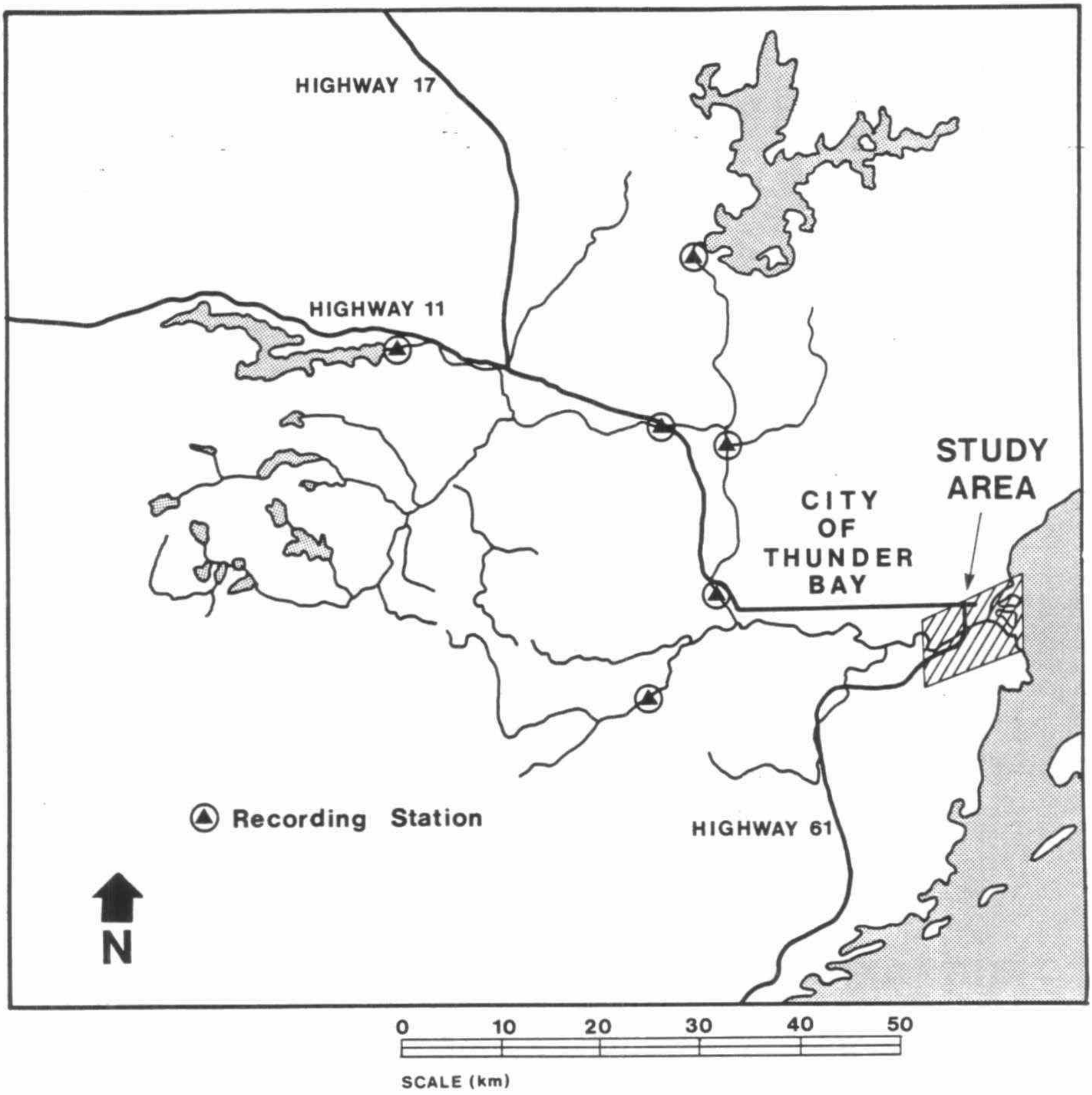


FIGURE 2.2: Streamflow Recording Stations.

gauge as there will be little inflow to the river between these stations under dry weather conditions.

From Figure 2.3 it can be seen that for the 7 - day average flow there is a shift in the relationship for recurrence intervals greater than 2 years. This is as expected due to the agreement with Hydro to maintain a minimum of 17 m^3/s. Utilizing the 7Q20 (7-day low flow with an average recurrence interval of 20 years) criterion for determining the design flow, yields 15.5 m^3/s as a minimum. While these two figures, the 7Q20 and the Hydro minimum, are not equal it is felt that the Hydro minimum can be used as the design flow for such a highly regulated system.

For the 1-day average flow figures a similar shift is apparent due to Hydro controls, however for recurrence intervals greater than 3 years the relationship has a slope similar to the region with recurrence intervals less than 1.3 years. This may reflect the difficulty in regulating the Kaministiquia River system to meet the minimum flow criterion on a daily basis under extreme dry weather conditions.

During the two survey periods, July 28 to August 1 and August 11 to August 15, Ontario Hydro was asked to regulate the system outside of normal operating procedures such that the minimum flow of 17 m^3/s would occur at Kakabeka Falls. Table 2.2 lists the observed flows for July and August 1986. It can be seen that a reasonable level of agreement with the Hydro minimum was achieved.

In order to quantify the amount of input to the river between Kakabeka Falls and the study reach, streamflow was metered at the City of Stanley. This location represents the first access point upstream of the backwater effect of Lake Superior. Two flow

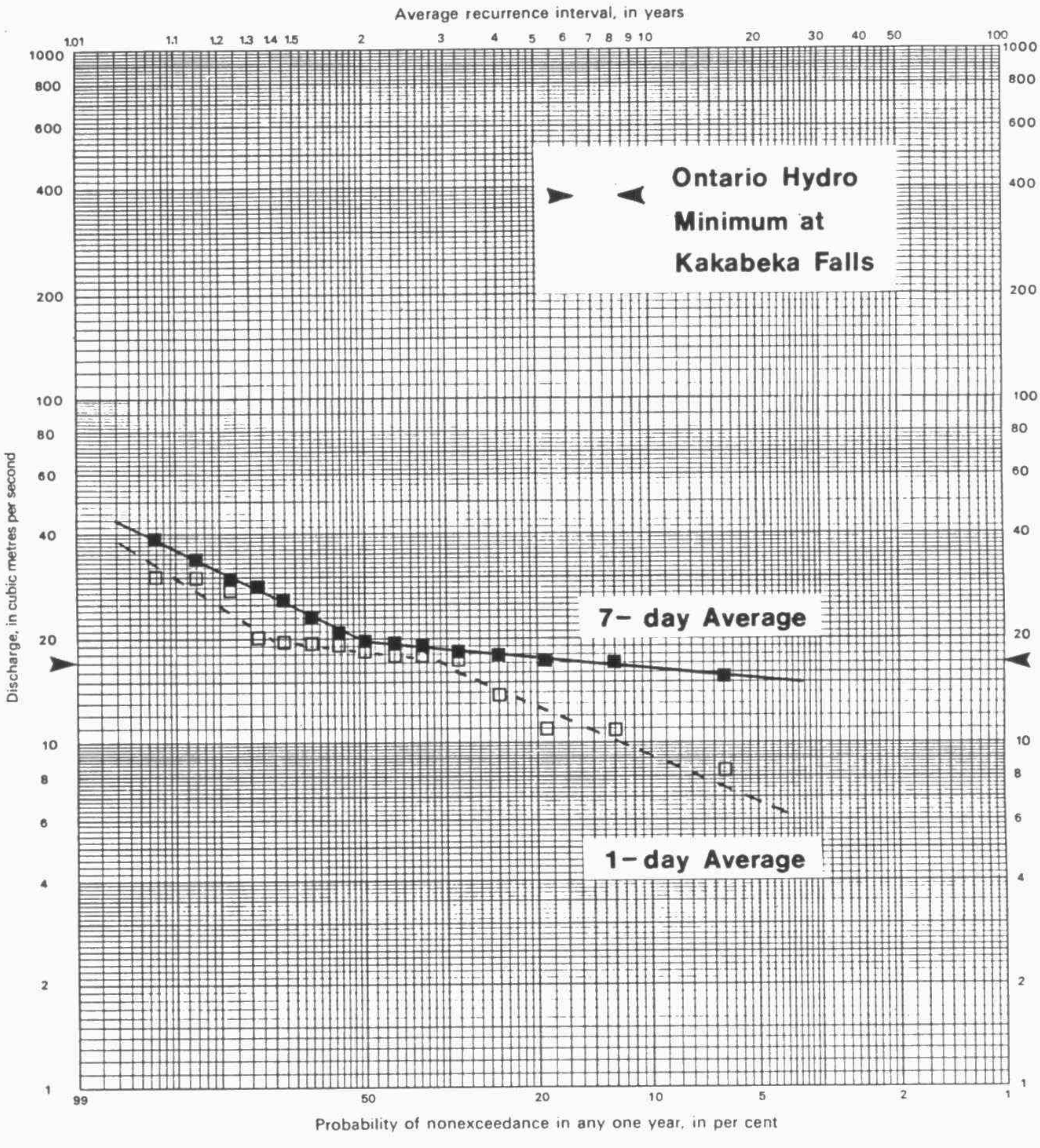


FIGURE 2.3: Average Streamflow Recurrence Interval-
Kaministiquia River At Kaministiquia.

TABLE 2.2

KAMINISTIQUIA RIVER STREAMFLOW AT KAKABEKA FALLS POWER HOUSE

DAILY DISCHARGE* IN CUBIC METRES PER SECOND		
DAY	JULY	AUG
1	83.1	42.1
2	95.8	47.3
3	94.5	47.2
4	105	45.7
5	114	43.5
6	110	43.9
7	111	44.7
8	109	42.3
9	88.3	44.6
10	76.5	41.2
11	66.3	19.7
12	72.0	18.1
13	69.8	18.1
14	70.0	17.6
15	69.8	19.1
16	69.1	27.4
17	56.9	27.4
18	60.2	26.2
19	72.9	34.3
20	69.6	34.4
21	69.2	35.8
22	69.2	30.4
23	65.1	31.3
24	86.1	29.6
25	78.7	29.3
26	69.1	30.8
27	68.3	29.3
28	52.0	28.3
29	21.6	28.9
30	18.0	31.3
31	22.0	29.9
TOTAL	2283.1	1019.7
MEAN	73.6	32.9
MAX	114	47.3
MIN	18.0	17.6

Summary for the year 1986

Mean discharge, 59.6 m^3/s
Total discharge, 1880000 dam^3
Maximum daily discharge, 229 m^3/s on April 30
Minimum daily discharge, 17.6 m^3/s on August 14

* Provisional records - Subject to revisions

measurements were taken, July 30 - 18.6 m^3/s and August 14 - 19.9 m^3/s. Comparison of these results with Table 2.2, shows an increase of flow of 0.6 to 2.3 m^3/s. A range of this magnitude may be a result of how the flows are measured. Those in Table 2.2 are daily averages, while those metered at Stanley are instantaneous measurements. For the purposes of further analysis and modelling, 20 m^3/s will be used as the design flow entering the study area (ie. at station A).

Attempts to meter streamflow within the study area were generally unsuccessful. Backwater effects as well as the intrusion of lake-water make the interpretation of results difficult. Portions of the data are extremely useful however, as measurements of velocity can be used in determining the time-of-travel between river stations. This will be explored further in the next section.

Effluent flow rates were also monitored during the survey and are presented in Table 2.3. It is evident that Great Lakes Forest Products, in terms of flow, constitutes almost the entire effluent input to the majority of the study area. The input from the sewage treatment plant, while large, impacts the river just prior to it entering the Thunder Bay Harbour. Thus it is of lower significance in terms of D.O. impact, since its' effect will take place outside of the study area.

2.3 Time-of-Travel

Time-of-travel may be determined for river reaches by one of several methods: 1) drogues; 2) velocity-distance methods; 3) tracers. The preferred method is the use of fluorescent tracer dyes. All three methods were utilized to some degree in the Kaministiquia River to overcome difficulties associated with backwater areas. The lower Kaministiquia River is also unique

TABLE 2.3

EFFLUENT FLOW RATES

DISCHARGER	CODE*	AVERAGE FLOW RATE (m^3/s)
Great Lakes Forest Products - Diffuser	GLA	1.91
- Clean Water Outfall	GLB	1.04
Reichhold Chemical	RC	0.004
Ogilvie Mills Limited	OM	0.008
Thunder Bay Sewage Treatment Plant	STP	1.11

* These codes are used throughout the report as abbreviated identifiers of the individual discharge points.

in that the dredging that has taken place allows colder and denser lakewater to intrude up the delta. As reported earlier (MOE, 1972) lakewater was found to underlie the river water as far upstream as the Westfort Turning Basin. Section 2.4 summaries the findings for the 1986 survey which found a similar stratification. Figure 2.4 provides a schematic representation of the lakewater intrusion.

In order to measure the relative movements of river and lake water, drogues were used at depths of 2, 4, and 6 metres. Table 2.4 summarizes the net velocities as calculated from drogue movements. As can be seen, the velocities of lake water indicate a net movement upstream. In order to maintain a mass balance there must be a degree of mixing of lake and river water along the entire study reacn underlaid by the lake water (as shown in Figure 2.4). The drogue results for the reaches below station G for river water velocities are considered unreliable. Depth profiles of temperature (Section 2.4) have shown the effective river depth to between 1 and 2 metres in this area, thus the drogues at a depth of 2m could not effectively measure the river velocity.

As reported in Section 2.2, streamflow measurements within the study reach can give an indication of velocities of the upper layer of river water. Table 2.5 presents results for these stations at which measurements were taken. Comparison of these results with Table 2.4 shows good agreement for those reaches between station C and station H. Measurements taken outside of this area are considered unreliable due to difficulties encountered with meter orientation and observation depths.

The tracer dye method yields times-of-travel directly, which are summarized in Table 2.6 along with calculated velocities for comparison purposes. The results show a good comparison in the lower reaches with the other methods. In the upper reaches the tracer method appears to over-estimate time-of-travel. This may be

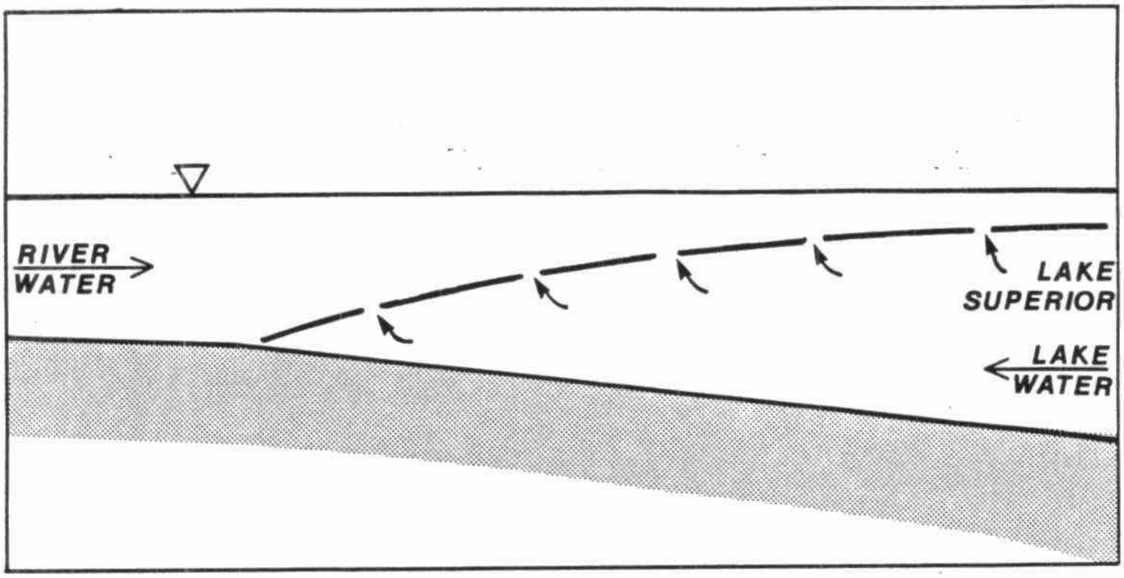


FIGURE 2.4: Schematic Diagram Of Lakewater Intrusion.

TABLE 2.4

STREAM VELOCITIES DROGUE METHOD

REACH	VELOCITY (m/s)			REACH AVERAGE*
	2m depth	4m depth	6m depth	
A - Diffuser	0.045	-	-	0.045
B - C	0.099	0.061	-	0.085
G - J	0.092	0.045	-0.011	0.069
J - K	0.041	0.026	-0.004	0.067
G - H	0.106	0.0	-0.012	0.106
L - M	0.0055	-0.0059	-0.020	0.0055

* river water only as determined from temperature profiles.

TABLE 2.5: RIVER WATER VELOCITIES

STATION	VELOCITY (m/s)
A	0.076
C	0.082
F	0.100
G	0.100
H	0.071
J	0.057
N	0.031

TABLE 2.6: TRACER DYE TIME-OF-TRAVEL

REACH	TIME-OF-TRAVEL (hrs.)	VELOCITY(m/s)
A-Diffuser	-	-
Diffuser-B	0.58	0.18
B-C	2.45	0.11
C-D	1.78	0.13
D-E	1.60	0.14
E-F	1.08	0.16
F-G	3.02	0.11
G-J	2.70	0.098
J-K	1.95	0.081
K-N	1.58	0.083
N-O	3.42	0.071
O-P	-	-
G-H	3.05	0.12
H-I	-	-
K-L	1.53	0.068
L-M	7.00	0.075

due to the fact that dye samples were collected within 1 metre of the surface while the effective depth of river water was in the range of 2 to 5 metres.

Table 2.7 presents a summary of the times-of-travel, and associated method, which were used in the modelling exercise (Section 2.6).

2.4 Field Data

As outlined in Section 1.4, field data (temperature, conductivity, pH, dissolved oxygen) were collected at all instream and effluent stations every four hours over a seventy-two hour period. Figure 2.5 summarizes the field data.

The temperature results show the impact of the warm water discharge from Great Lakes Forest Products which raises the river temperature which then slowly declines towards the lake. Mean temperatures are in the range of 18-21°C.

Conductivity shows a similar response, increasing at the diffuser then decreasing towards the lake. The reasons for a conductivity decrease are somewhat different than for the temperature data. Temperature will decrease as heat is lost to the atmosphere. Conductivity, which is generally considered a conservative parameter, can only decrease by the addition of dilution water with lower conductivity. The decrease in conductivity lends support to the hypothesis that lake water underlying the river water is mixing in an upward direction with the river water.

The pH profile generally shows little impact, with means in the range 7 - 7.5. The Dissolved Oxygen (D.O) profile shows the classical response to the input of oxygen consuming wastes. The sag (point of minimum D.O.) occurs generally from Station G to Station K. Mean D.O. values reach extremes of 3 mg/l while

TABLE 2.7

TIME-OF-TRAVEL SUMMARY

REACH	METHOD	TIME-OF-TRAVEL
A-Diffuser	drogue	6.52
Diffuser-B	*	2.33
B-C	*	6.21
C-D	velocity-distance	2.86
D-E	*	2.83
E-F	velocity-distance	1.73
F-G	*	3.37
G-J	tracer dye	2.70
J-K	tracer dye	1.95
K-N	tracer dye	1.58
N-O	tracer dye	3.42
O-P	*	4.41
G-H	velocity-distance	5.11
H-I	*	5.51
K-L	tracer dye	1.53
L-M	tracer dye	7.00

* time-of-travel determined by extrapolating velocity from reach immediately upstream.

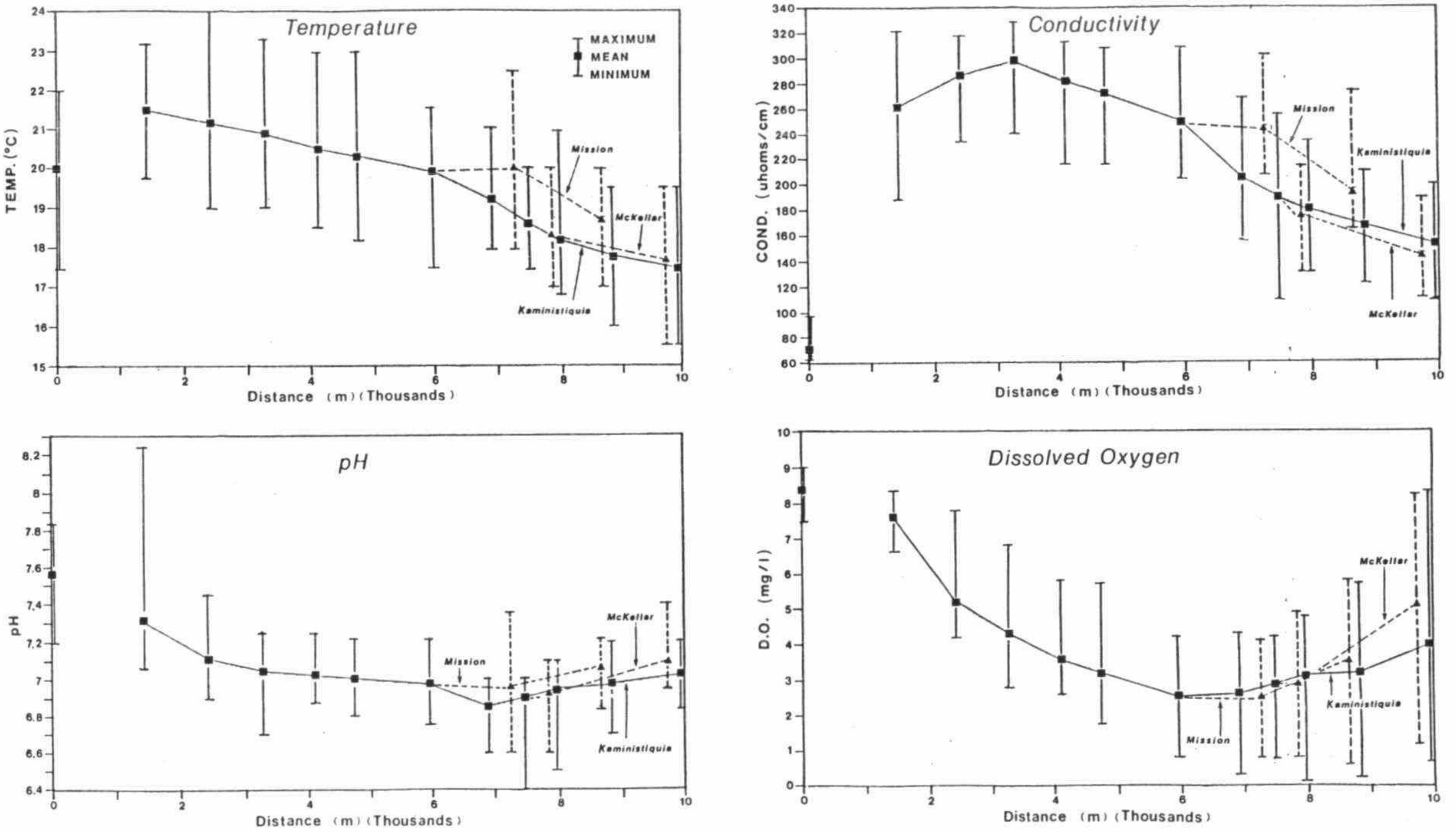


FIGURE 2.5: Field Data.

minimum D.O.'s reach extremes of 0.2 mg/l. Of note is the fact that the maximum D.O's in the sag are below the MOE objective of 5 mg/l which is considered the concentration necessary to protect biota (MOE, 1984).

In addition to collecting field measurements of D.O. every 4 hours, continuous D.O. recorders were installed at 6 of the river stations. The data is summarized in Appendix A. The profiles show good agreement with the field data with the sag occurring at station G with an extreme of 0.40 mg/l.

Depth profiles of temperature and dissolved oxygen were taken at all but two of the stations. Equipment difficulties limited the data collection to a single profile at each station. Figure 2.6 illustrates several typical profiles. The complete data set is contained in Appendix B. The temperature profiles show the strong stratification of river and lake water in the study area. Surface temperatures in the 20°C range are in sharp contrast to the lake. The D.O. profiles show a similar pattern with warm oxygen depleted river water overlying colder oxygen rich lake water. The sag in D.O. concentration again is shown to be downstream of Station G. River water D.O. levels within the sag region do not show similar extremes as the field values reported above, but are within the observed ranges. This is a result of the profiling being single time measurements whereas the field values were measured over a 72 hour period.

2.5 Water Quality Data

In addition to field measurements of water quality, samples were taken every 8 hours during the 72-hour survey and were analysed for an extensive list of parameters as outlined in Table 1.1. Figure 2.7 illustrates several profiles. The complete data set is contained in Appendix C.

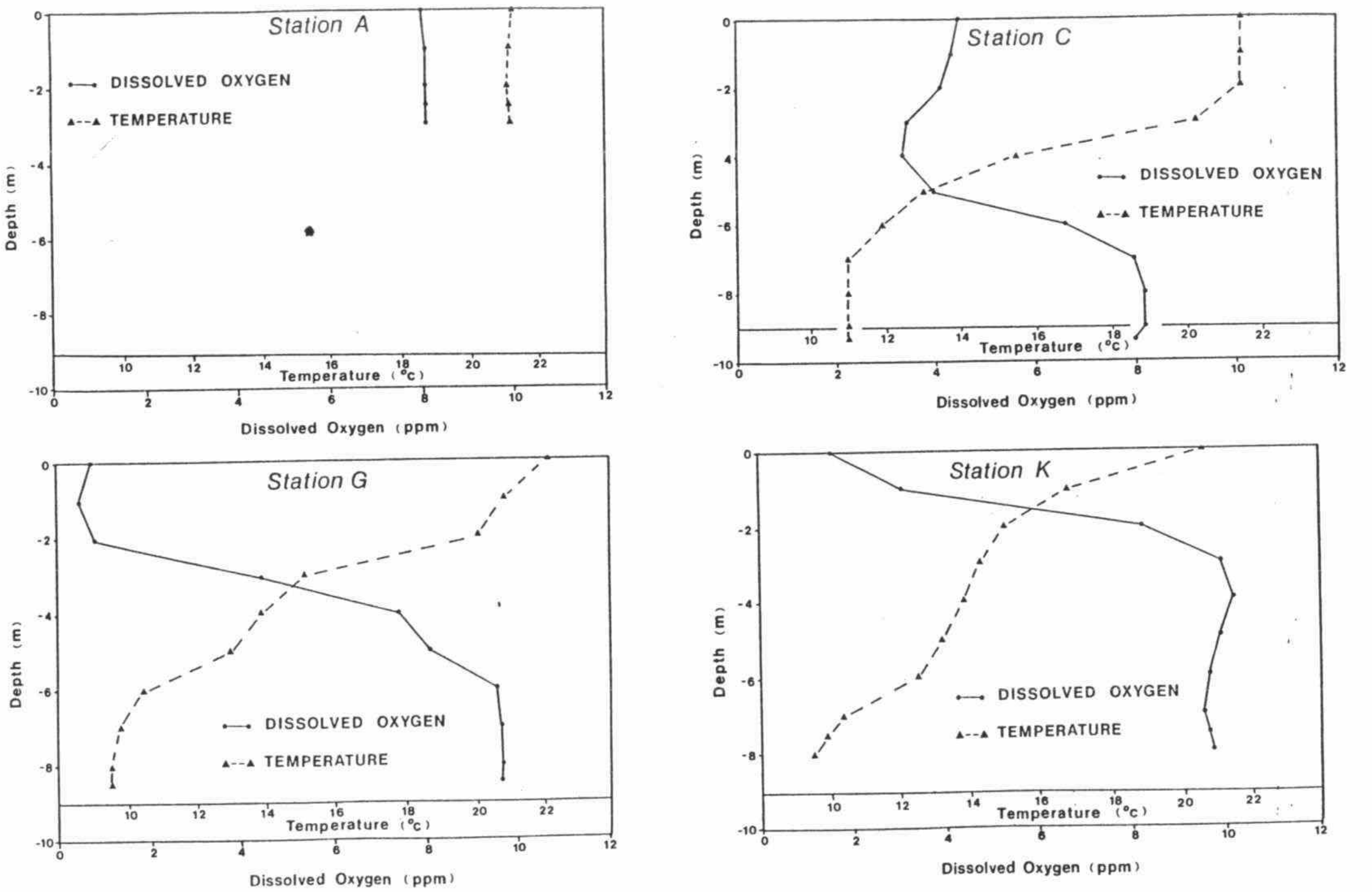


FIGURE 2.6: Temperature and Dissolved Oxygen Depth Profiles.

It can be seen that in general the largest impact is due to Great Lakes Forest Products. BOD_5 increases from less than 1 mg/l to 23 mg/l just below the diffuser outfall. Notable exceptions to the large impact of Great Lakes Forest Products occur for the Nitrogen and Phosphorus parameters which also show impacts due to Ogilvie Mills Limited and the Sewage Treatment Plant.

An analysis of parameter concentrations for which a Provincial Water Quality Objective (PWQO) exists, shows that only total phosphorus and D.O. exceed the criteria. Great Lakes Forest Products, Ogilvie Mills Limited and the Sewage Treatment Plant have significant discharges of phosphorus. The discharge of oxygen consuming wastes appears to be of concern to Great Lakes Forest Products only.

Examination of the effluent concentrations shows those of Ogilvie Mills Limited and Reichhold Chemical to be generally up to an order of magnitude greater than those at Great Lakes Forest Products. The greater impact of Great Lakes is due to its effluent volume being three orders of magnitude greater than that of Ogilvie Mills Limited and Reichhold Chemical. Table 2.8 presents a loading summary by point source discharger.

Appendix C also contains results for cross-river sampling at stations B, K and P. Three samples were collected at equally spaced points across the river in order to detect the presence of a mixing zone below the effluent discharge points. The data shows that no significant cross-stream gradients exist. This is as expected for Great Lakes Forest Products due to the use of a diffuser outfall. The Sewage Treatment Plant also utilizes a diffuser. The results near the Ogilvie Mills bank outfall are slightly anomalous. The lack of a cross-stream gradient may be

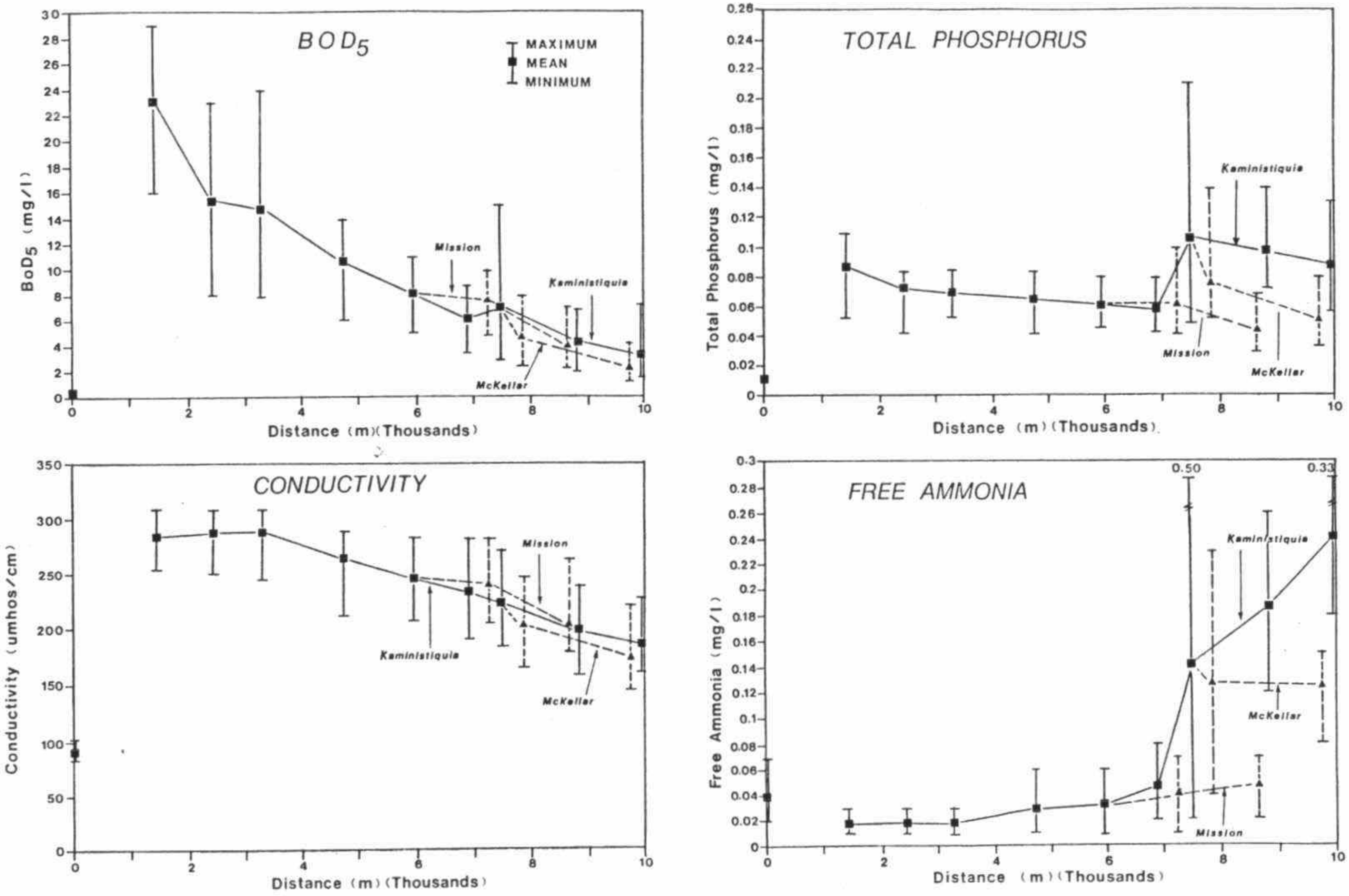


FIGURE 2.7: Water Quality Data.

TABLE 2.8: Effluent Loads

	GLA	GLB	RC	OM	STP
Flow (m^3/s)	1.91	1.04	0.004	0.008	1.11
BOD_5 (mg/l)	283	1.28	29.4	478	54.9
(kg/day) x 1000	46.7	0.11	0.0104	0.32	5.26
Suspended Solids (mg/l)	72	2.4	157	1310	39.0
(kg/day) x 1000	11.9	0.21	0.054	0.87	3.73
Total Phosphorus (mg/l)	0.89	0.024	2.05	117	1.35
(kg/day) x 1000	0.14	0.0023	0.0009	0.077	0.13

due to the relatively small load and that the load is impacting on an area already affected by Great Lakes Forest Products.

2.6 B.O.D. - D.O. Modelling

The MOE steady state D.O. model, DOMOD3, was utilized to simulate the behaviour of D.O. within the study area. The DOMOD3 model is based on modified form of the Streeter-Phelps equation and is described in detail the Stream Water Quality Assessment Procedures Manual (MOE, 1980). DOMOD3 is a one-dimensional model to be used in river situations. The lower Kaministiquia river, as described earlier, behaves as an estuary with warm river water overlying colder lake water. In applying DOMOD3 to the study area, only the river water was simulated.

The MOE steady state model considers the following processes: decomposition of carbonaceous and nitrogenous wastes, sediment oxygen demand, algae and plant respiration and photosynthesis, and atmospheric rearation. Photosynthetic and respirative effects were excluded from the model of lower Kaministiquia due to the absence of plants. Also, no significant diurnal fluctuations in D.O. were observed. Due to the presence of the water intrusion, sediment oxygen demand was only considered for the reach from the diffuser to Station B. A complete description of the model set-up and parameter estimation is contained in Appendix D.

Figure 2.8 shows the observed and predicted, BOD_5 and D.O. con-concentrations. Both curves show good agreement with the observed values. The observed values were taken as the extremes of the field data as described in Section 2.4. The lack of additional field data under different flow and/or loading conditions does not

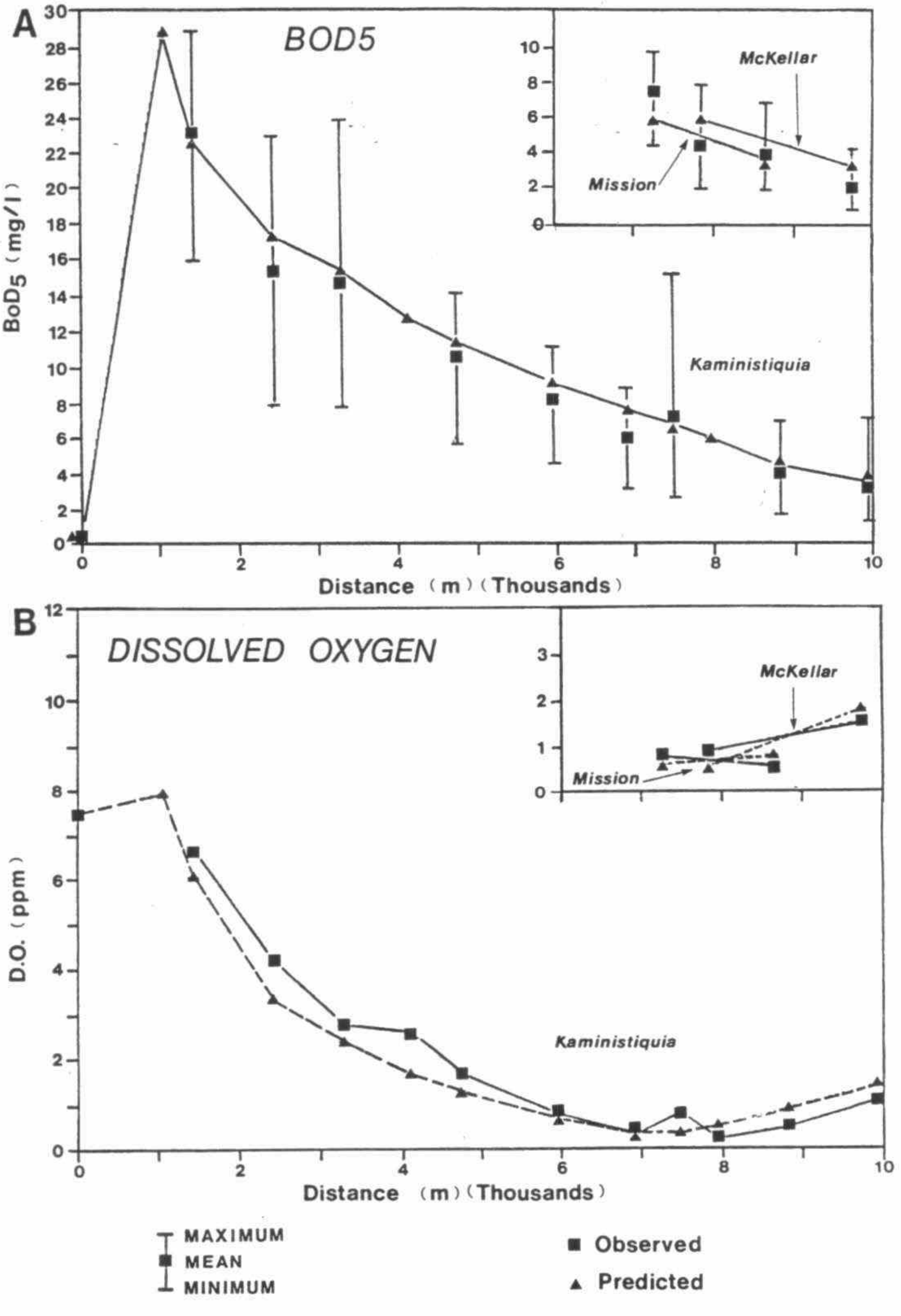


FIGURE 2.8: D.O. Modelling Results.

allow verification of the model. However, comparison with results from the 1970 survey, described subsequently, lend support to the model.

In order to determine the significance of the discharges from Reichhold Chemical and Ogilvie Mills Limited, the model was run with only the discharge from Great Lakes Forest Products present. The results show that Reichhold Chemical and Ogilvie Mills Limited do not significantly the alter D.O. response of the lower Kaministiquia River as it is affected by Great Lakes Forest Products (see Appendix D). The next step in the modelling exercise is to reduce the effluent loading in a step-wise manner and determine the D.O. response. From this analysis the required effluent load required to achieve acceptable D.O. concentrations can be determined. Figure 2.9 presents the results for a 30%, 50% and 75% reduction in the load of oxygen consuming material (BOD) from Great Lakes Forest Products. A reduction in BOD load can be achieved by reducing BOD concentrations, reducing flow or more likely a combination of both. Figure 2.10 provides a guide for the changes in BOD and/or flow required to achieve a load reduction. In the 1972 MOE report a figure was developed to show the allowable effluent loads, at varying streamflows, required to achieve specific D.O. concentrations at the sag point in the lower Kaministiquia River. Figure 2.11 is a reproduction of this figure and also contains the data developed from the present modelling exercise. Good agreement is shown between the present results and those from 1972.

Utilizing the Ontario Hydro Minimum flow of $17 m^3/s$ (600 cfs), which corresponds to a flow of $20\ m^3/s$ (700 cfs) within the study reach, yields an acceptable BOD_5 loading of 11.3 tonnes/day (25,000 lbs/day). This represents a 75% reduction in BOD loading from Great Lakes Forest Products. The sensitivity of the D.O. response to flow shows that increasing the study area flow to

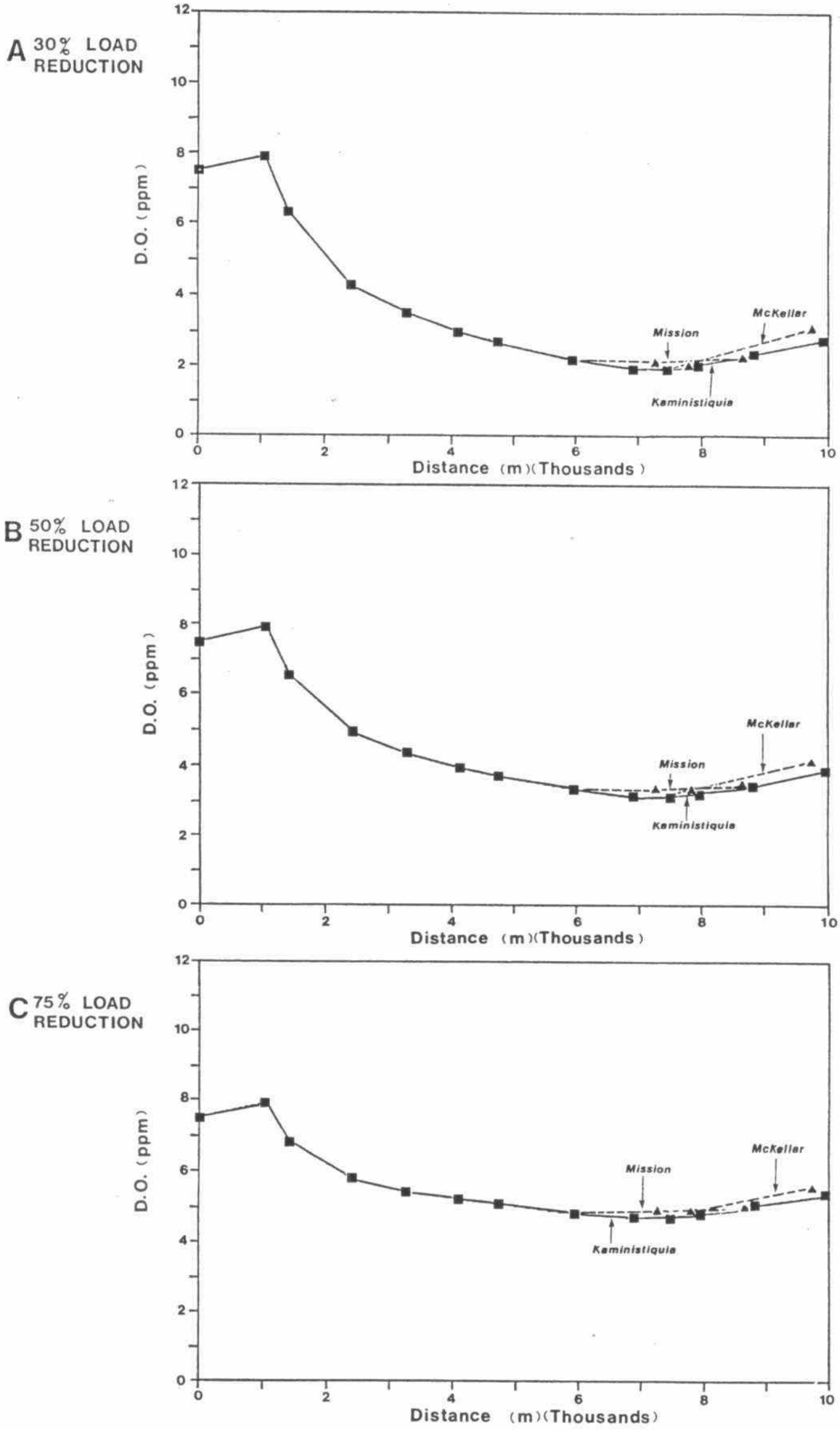


FIGURE 2.9: D.O. Response Under Varying Load Conditions.

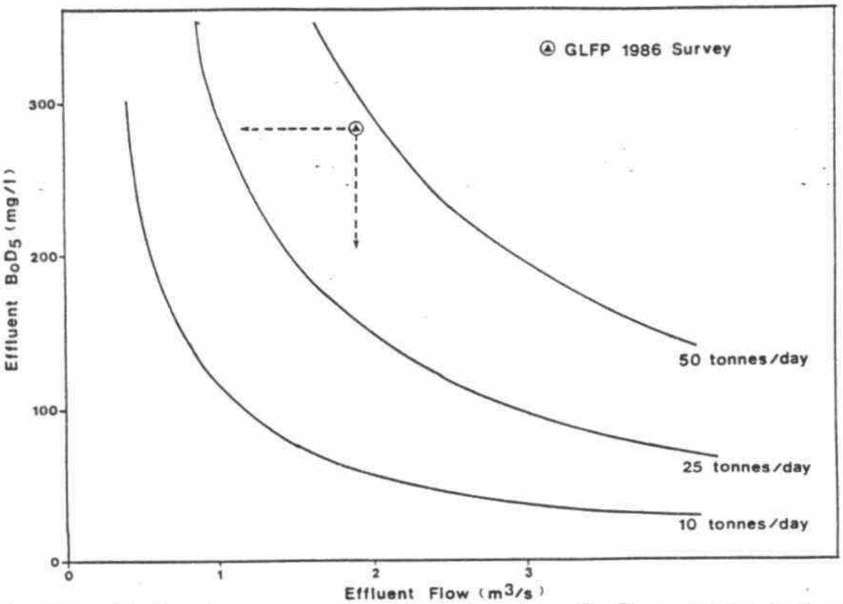


FIGURE 2.10: BoD5 Load as a Function of Concentration and Flow

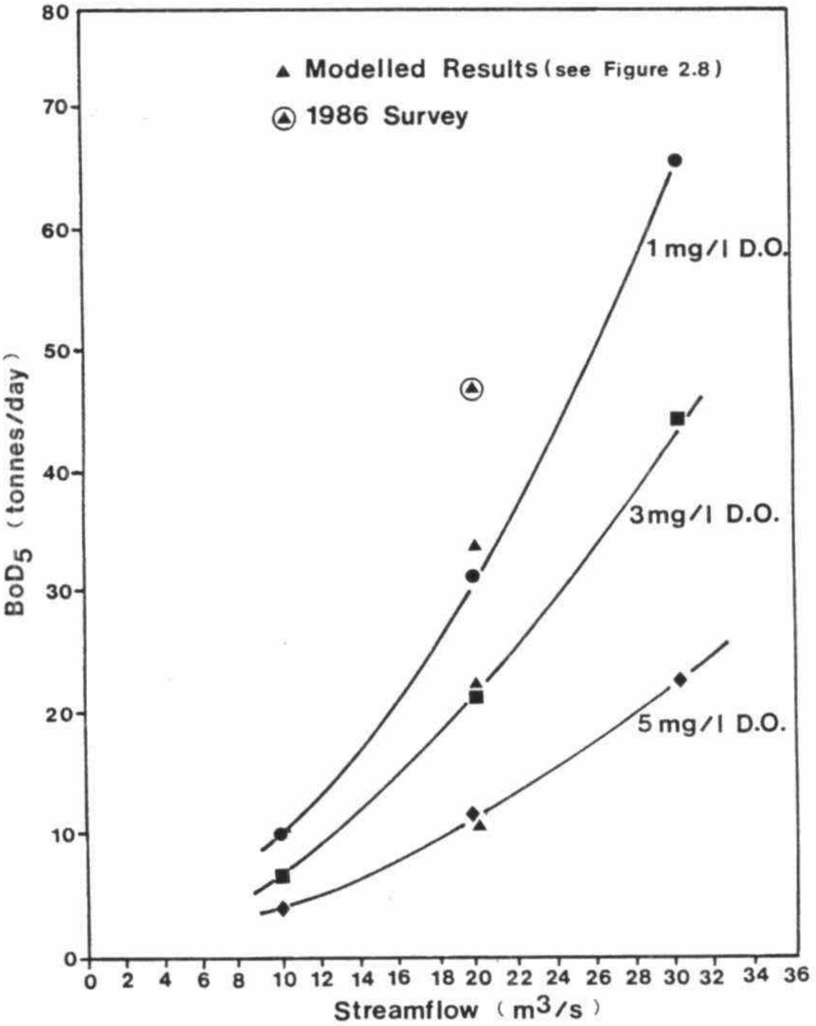


FIGURE 2.11: Allowable Effluent Loads.

30 m^3/s (1050 cfs) would require a load reduction of 50% (ie. 22.7 tonnes (50,000 lbs.) BOD_5 per day). The possibility of providing additional low flow augmentation should be investigated.

A load of 11.9 tonnes/day (26,200 lbs./day) has been estimated as the U.S. Environmental Protection Agency Limit for Great Lakes Forest Products (MOE, 1987). If this represents the Best Available Treatment (B.A.T.), then the receiving water impacts will be adequately addressed for BOD wastes.

REFERENCES

MOE, 1972 "Thunder Bay - Regional Water Quality Survey", September 1972.

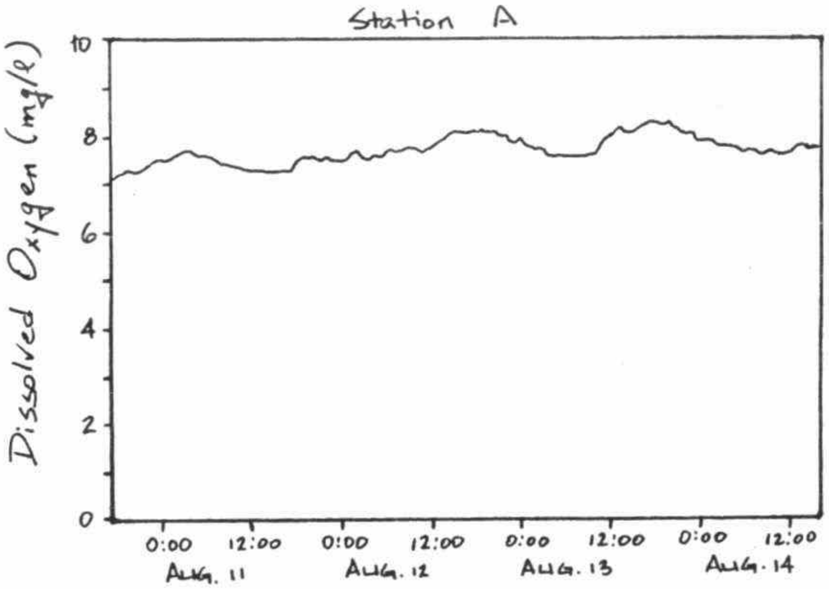
MOE, 1980 "Stream Water Quality Assessment Procedures Manual" March 1980.

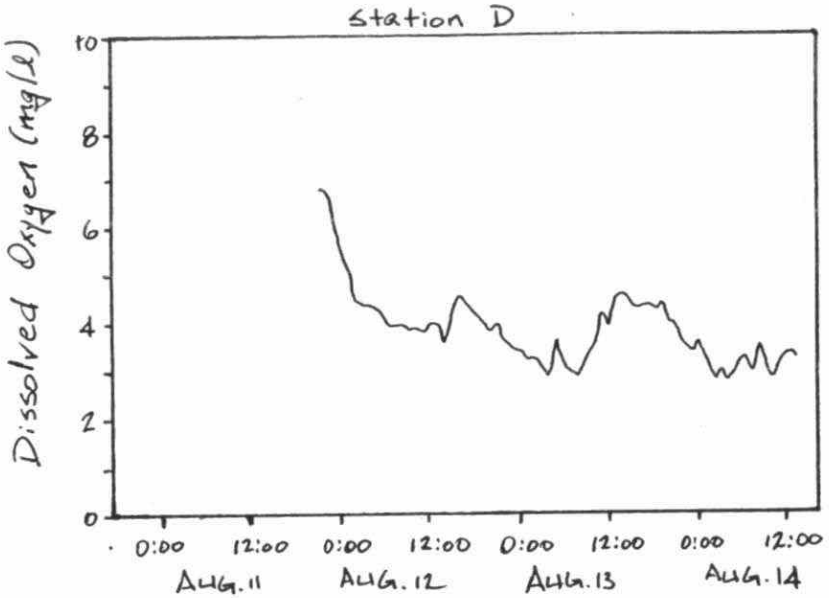
MOE, 1984 "Water Management - Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment", Revised May 1984.

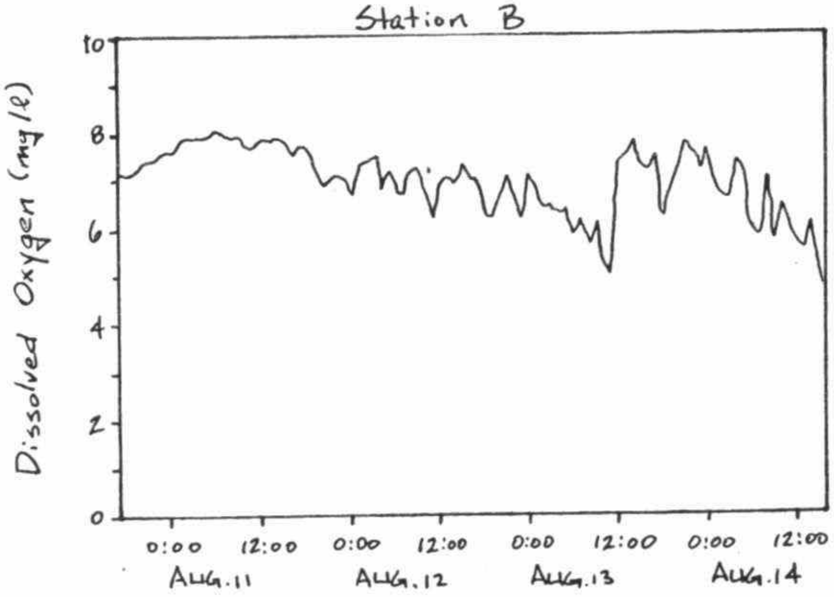
MOE, 1987 "Report on the 1986 Industrial Direct Discharges in Ontario", October 1987.

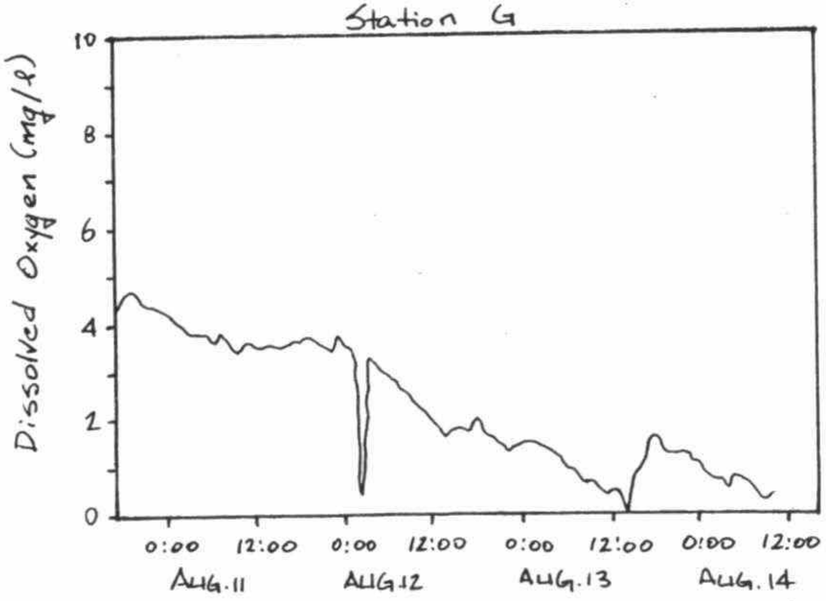
APPENDIX A:

CONTINUOUS D.O. RECORDS


Station A


Station D


Station B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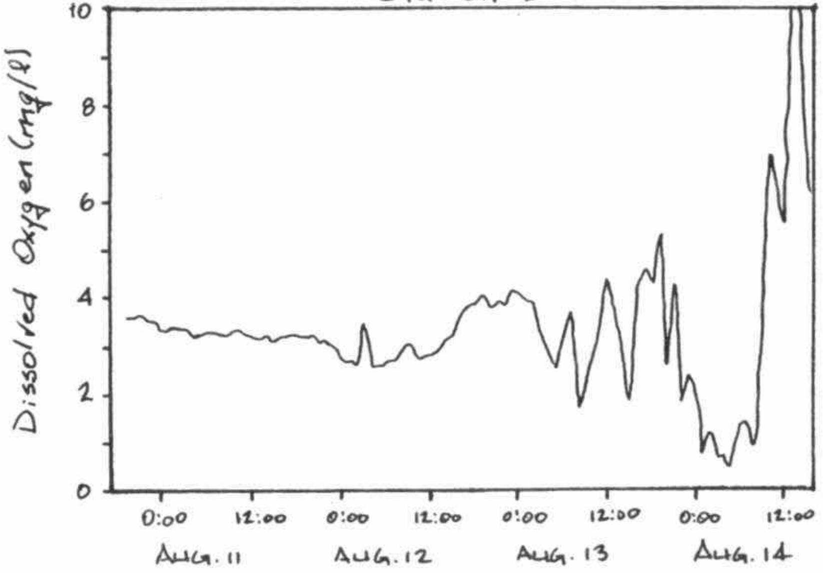
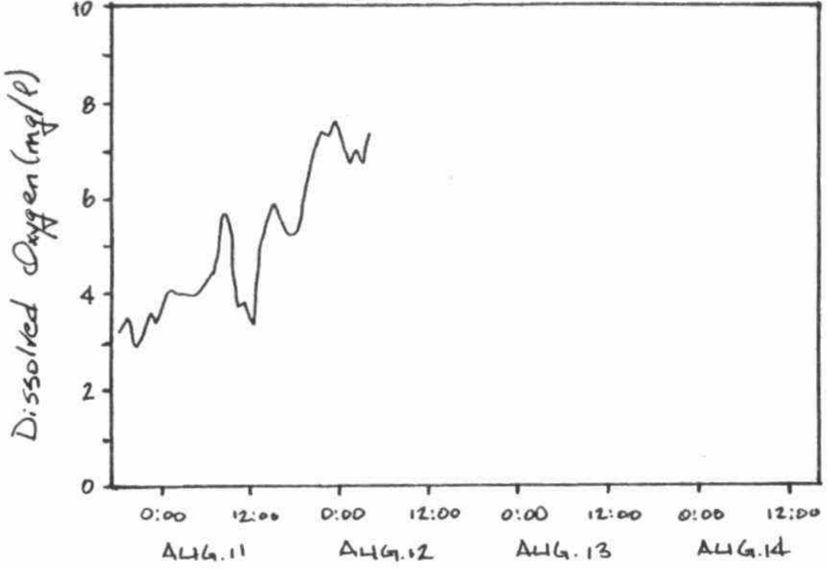
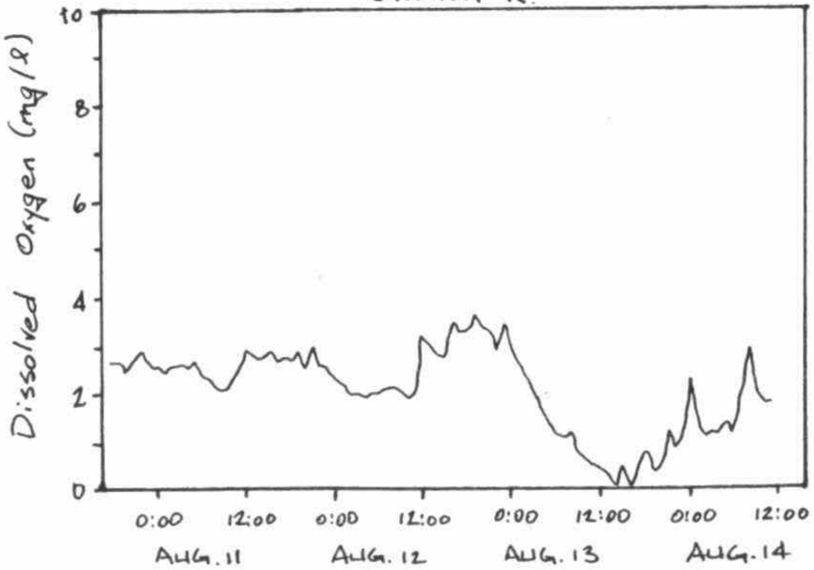
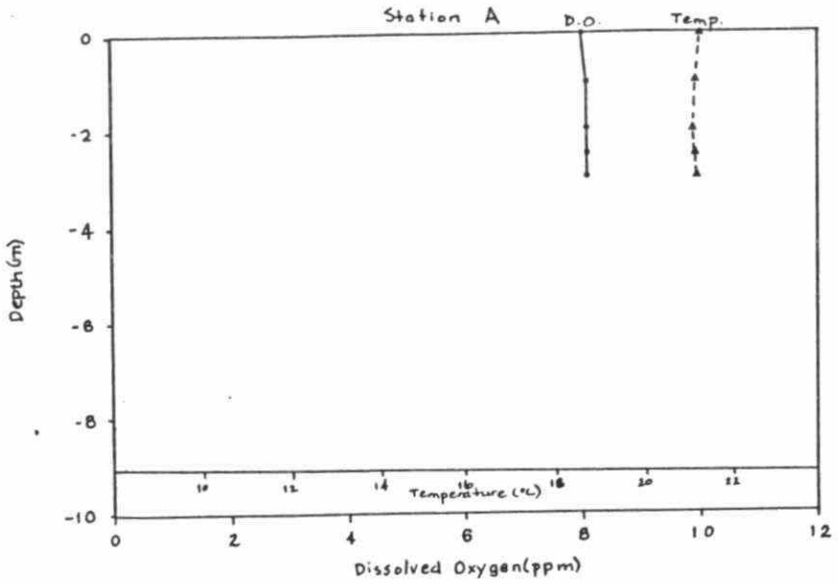

Station I

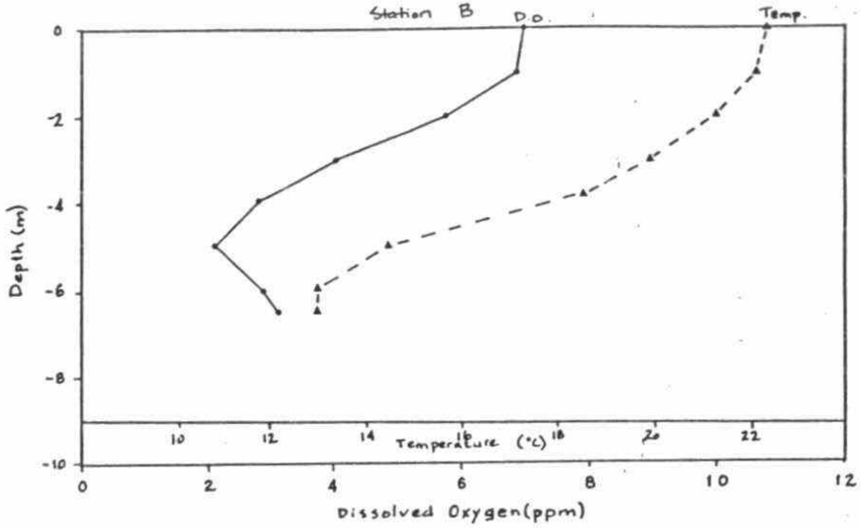

Station P

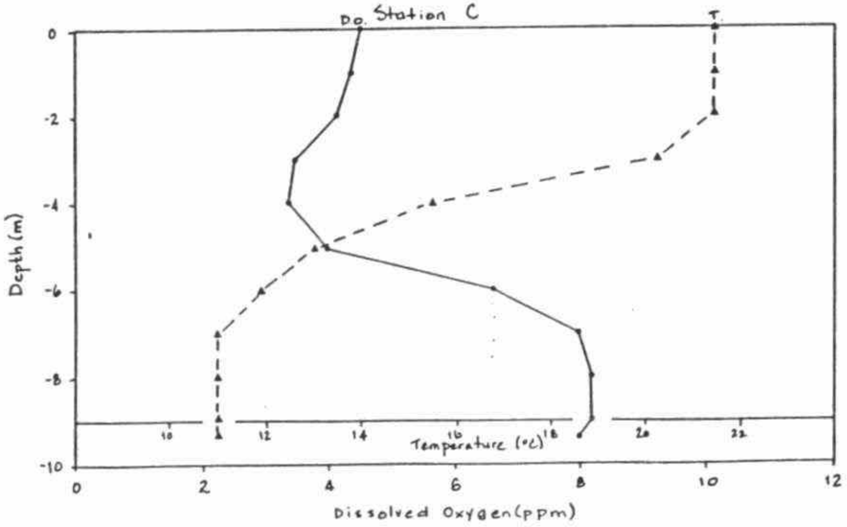

Station K

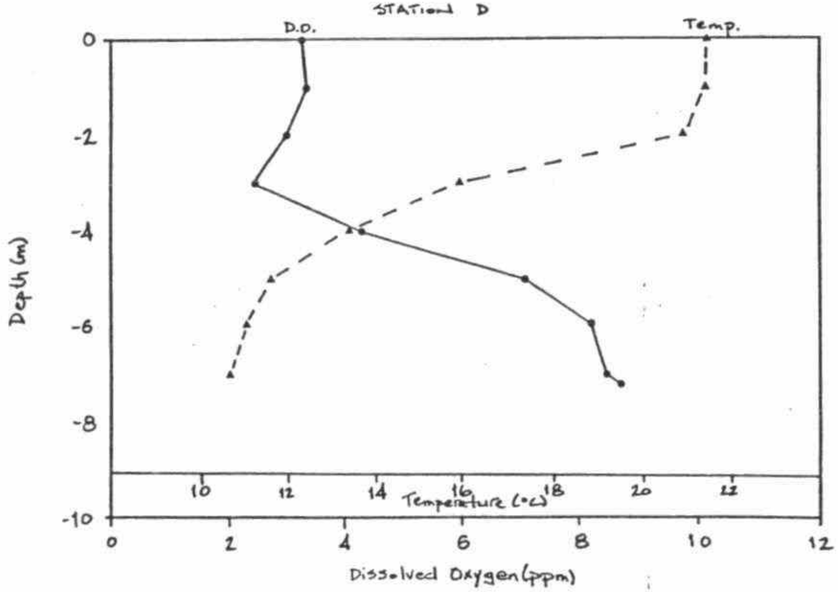
APPENDIX B:

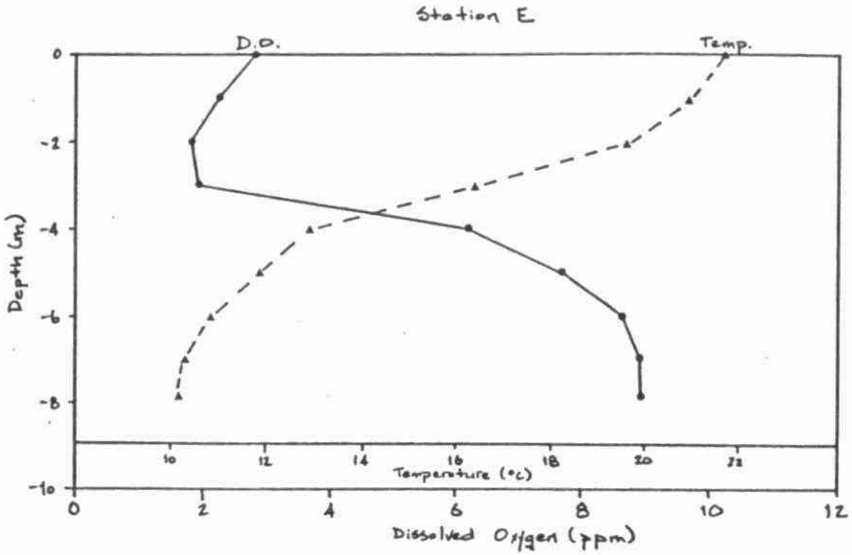
D.O. AND TEMPERATURE DEPTH PROFILES

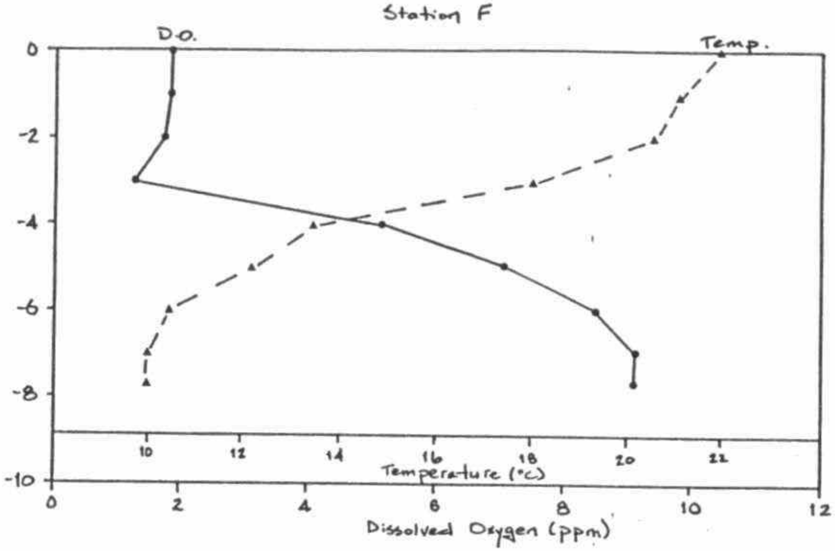

Station A
D.O.
Temp.
0
-2
-4
-6
-8
-10
Depth (m)
10
12
14
16
18
20
22
Temperature (°C)
0
2
4
6
8
10
12
Dissolved Oxygen(ppm)

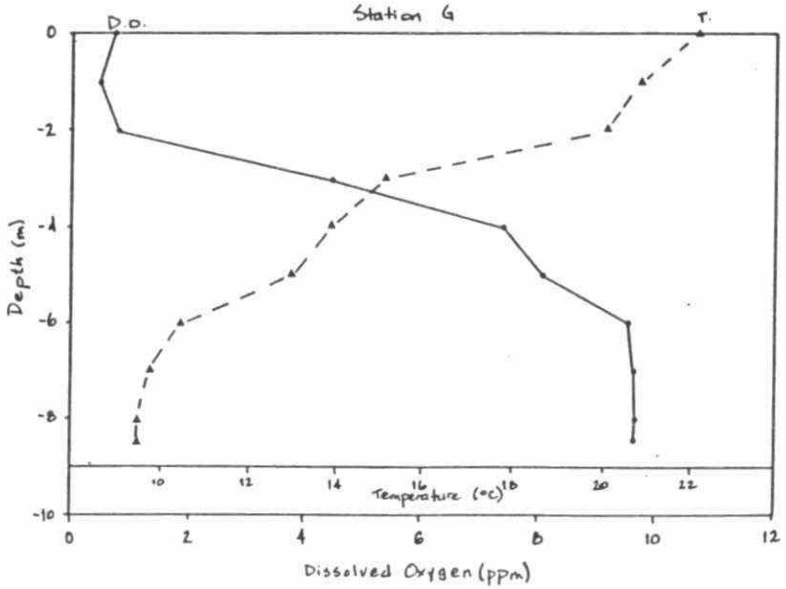

Station B
D.O.
Temp.
0
-2
-4
-6
-8
-10
Depth (m)
10
12
14
16
18
20
22
Temperature (°C)
0
2
4
6
8
10
12
Dissolved Oxygen(ppm)

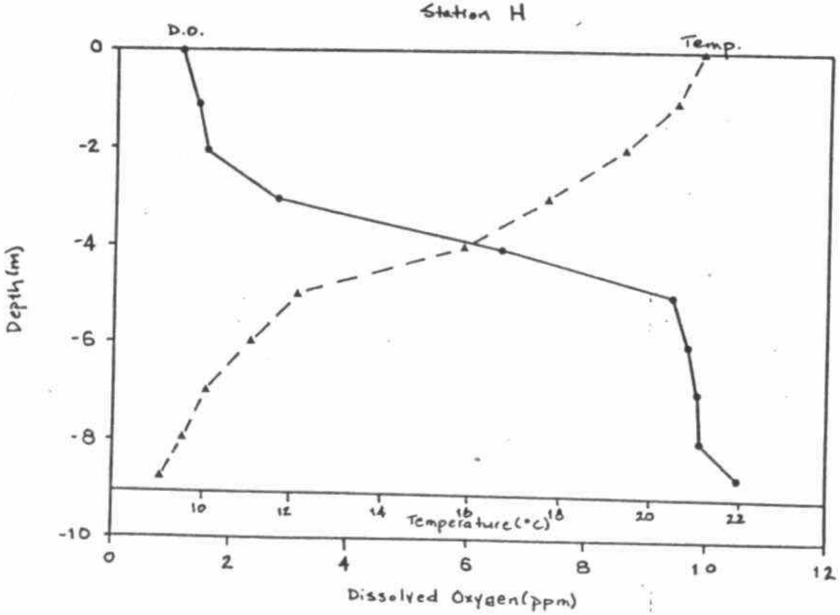

Station C
D.O.
T.
0
-2
-4
-6
-8
-10
Depth (m)
10
12
14
16
18
20
22
Temperature (°C)
0
2
4
6
8
10
12
Dissolved Oxygen(ppm)


STATION D
D.O.
Temp.
0
-2
-4
-6
-8
-10
Depth (m)
10
12
14
16
18
20
22
Temperature (°C)
0
2
4
6
8
10
12
Dissolved Oxygen(ppm)


Station E
D.O.
Temp.
Depth (m)
0
-2
-4
-6
-8
-10
10
12
14
16
18
20
22
Temperature (°c)
0
2
4
6
8
10
12
Dissolved Oxygen (ppm)


Station F
D.O.
Temp.
0
-2
-4
-6
-8
-10
10
12
14
16
18
20
22
Temperature (°c)
0
2
4
6
8
10
12
Dissolved Oxygen (ppm)


Station G
D.O.
T.
Depth (m)
0
-2
-4
-6
-8
-10
10
12
14
16
18
20
22
Temperature (°c)
0
2
4
6
8
10
12
Dissolved Oxygen (ppm)


Station H
D.O.
Temp.
Depth (m)
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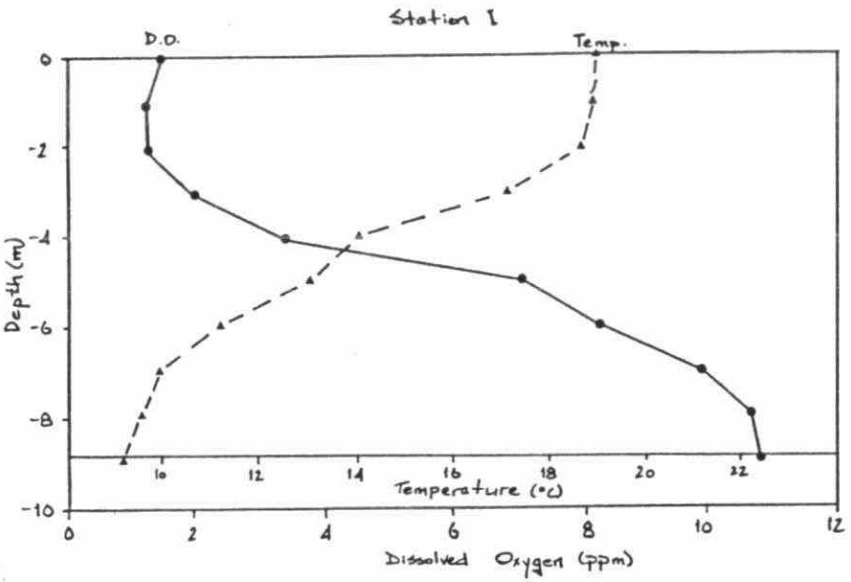
-2
-4
-6
-8
-10
10
12
14
16
18
20
22
Temperature (°c)
0
2
4
6
8
10
12
Dissolved Oxygen (ppm)


Station I
D.O.
Temp.
Depth (m)
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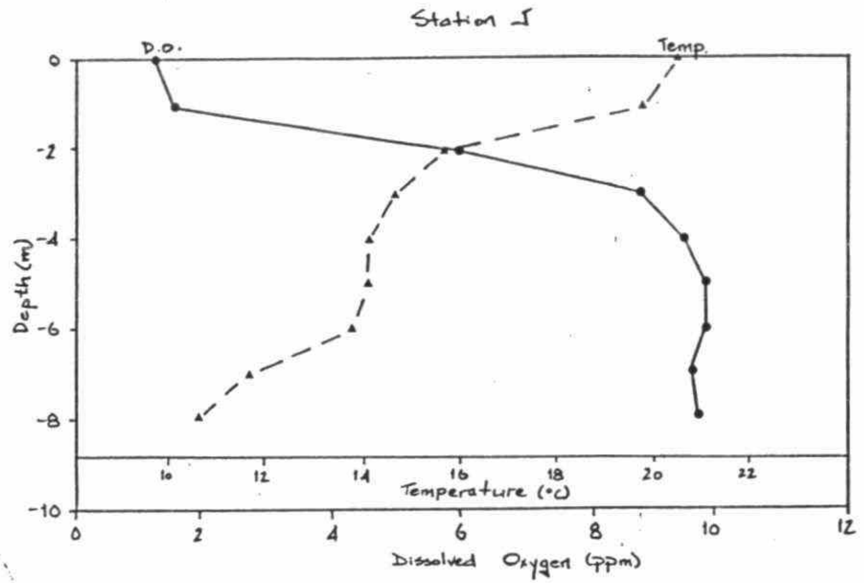
-2
-4
-6
-8
-10
10
12
14
16
18
20
22
Temperature (°C)
0
2
4
6
8
10
12
Dissolved Oxygen (ppm)


Station J
D.O.
Temp.
Depth (m)
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-2
-4
-6
-8
-10
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20
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Temperature (°C)
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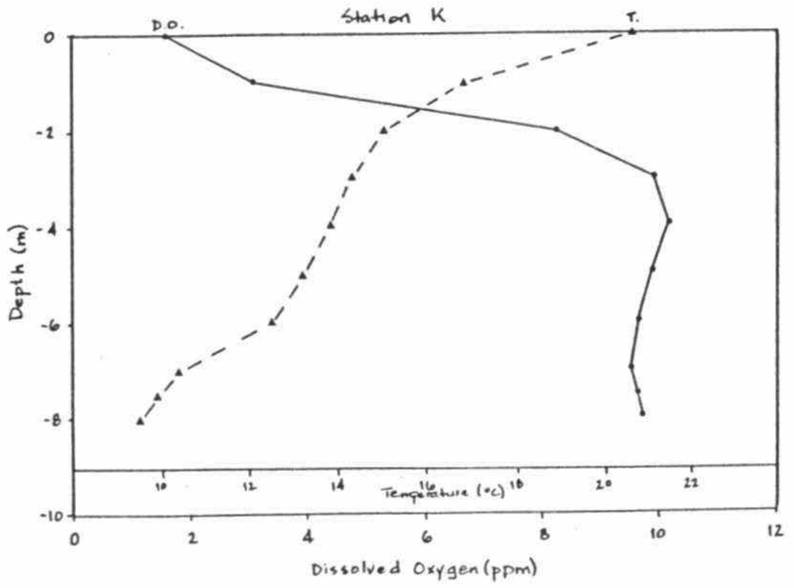
2
4
6
8
10
12
Dissolved Oxygen (ppm)


Station K
D.O.
T.
Depth (m)
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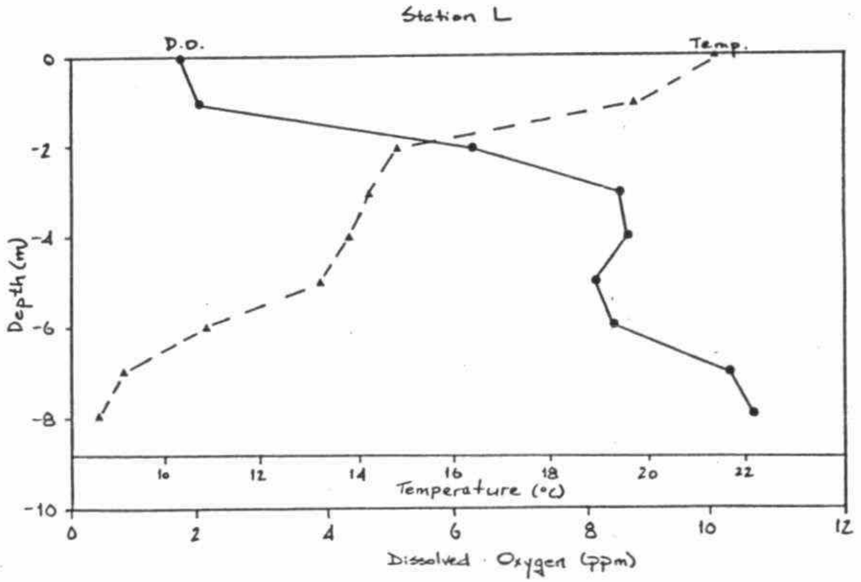
-2
-4
-6
-8
-10
10
12
14
16
18
20
22
Temperature (°C)
0
2
4
6
8
10
12
Dissolved Oxygen (ppm)


Station L
D.O.
Temp.
Depth (m)
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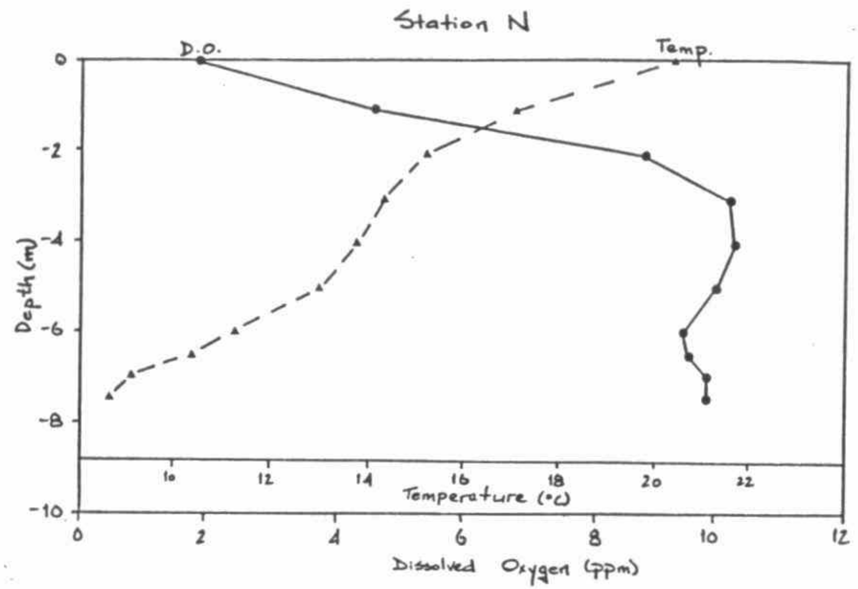
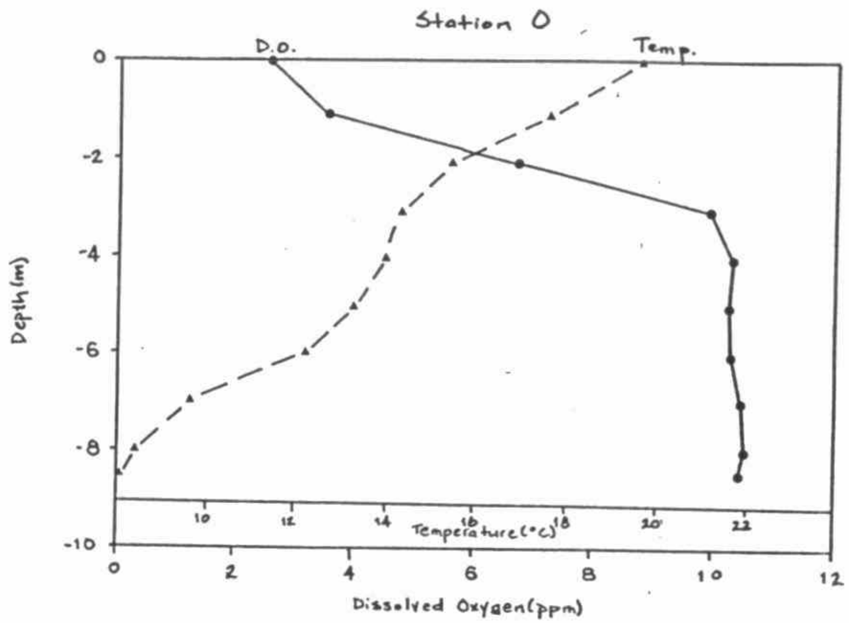
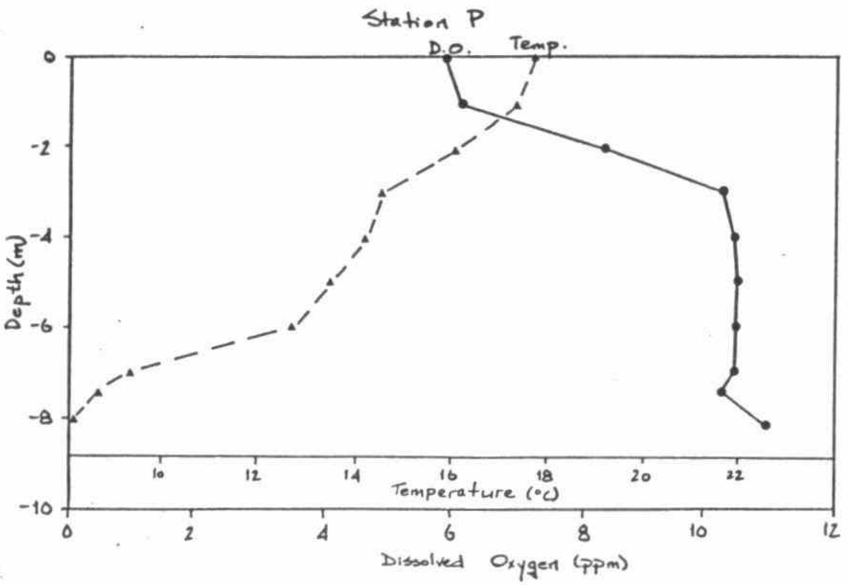
-2
-4
-6
-8
-10
10
12
14
16
18
20
22
Temperature (°C)
0
2
4
6
8
10
12
Dissolved Oxygen (ppm)



Station N



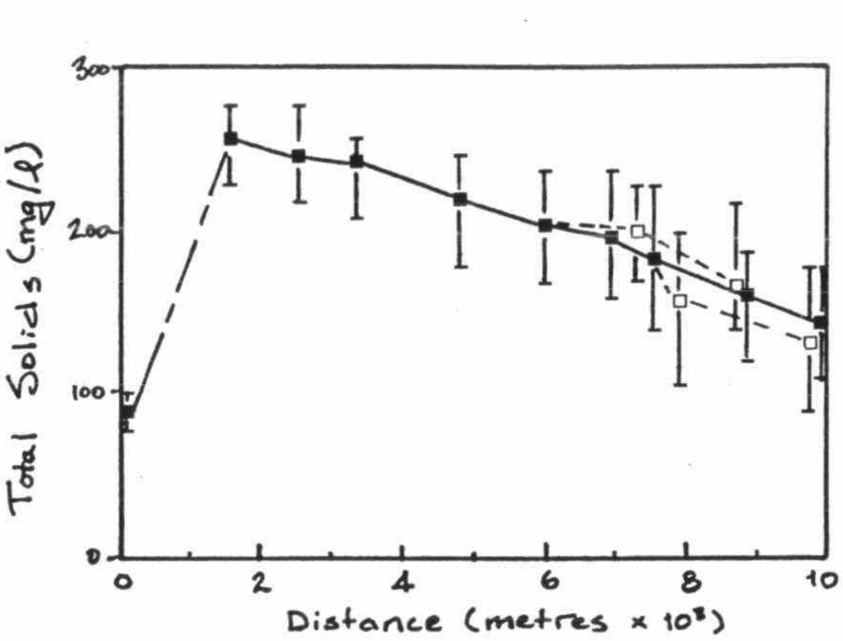
Station O

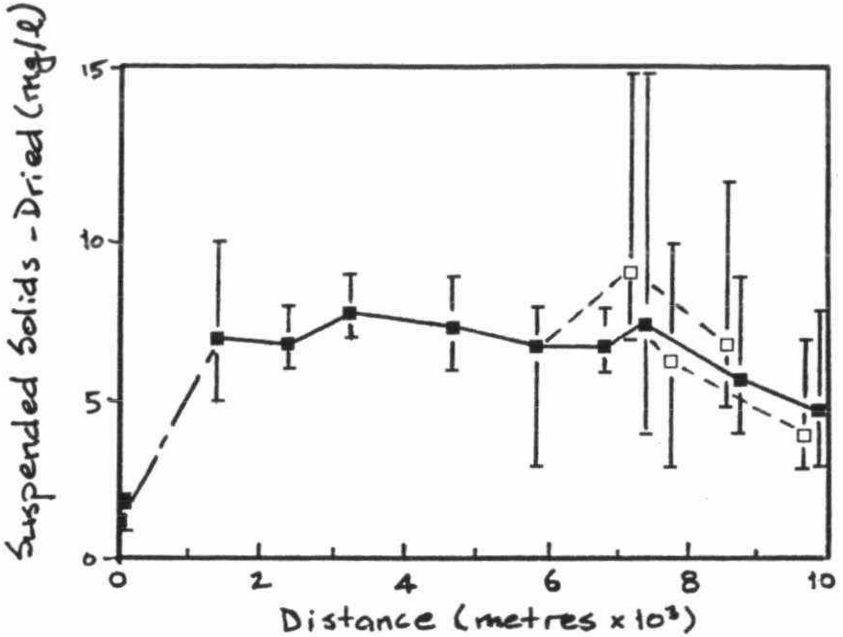


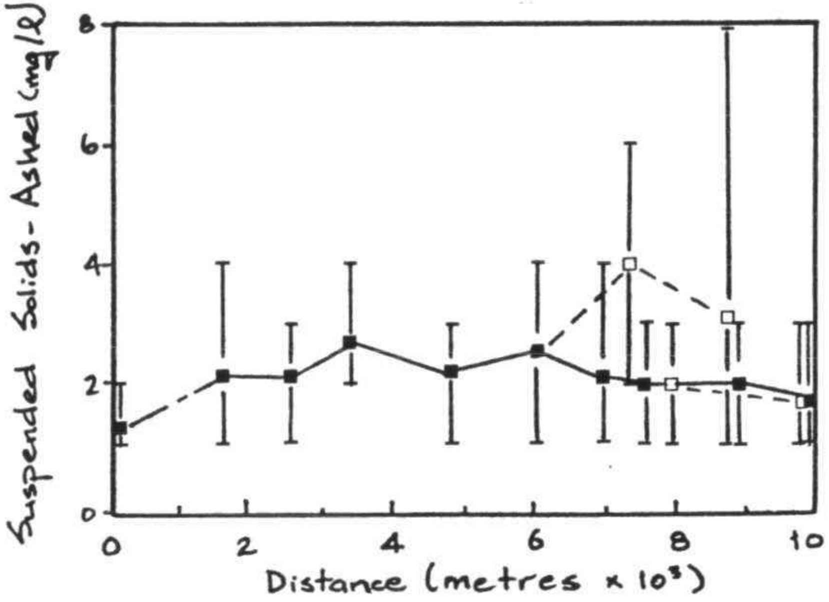
Station P

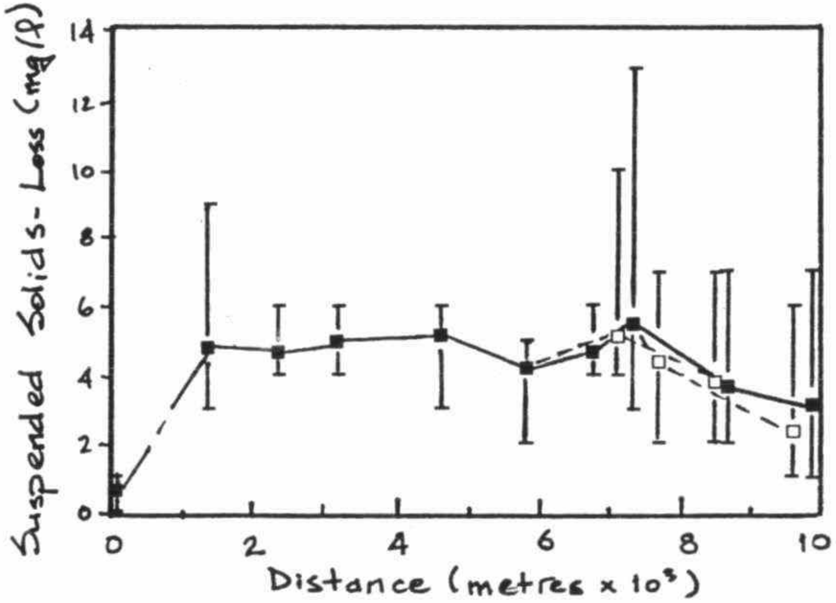
APPENDIX C:

WATER QUALITY DATA


Total Solids (mg/ℓ)
300
200
100
0
0
2
4
6
8
10
Distance (metres x 10³)


Suspended Solids - Dried (mg/ℓ)
15
10
5
0
0
2
4
6
8
10
Distance (metres x 10³)


Suspended Solids - Ashed (mg/ℓ)
8
6
4
2
0
0
2
4
6
8
10
Distance (metres x 10³)


Suspended Solids - Loss (mg/ℓ)
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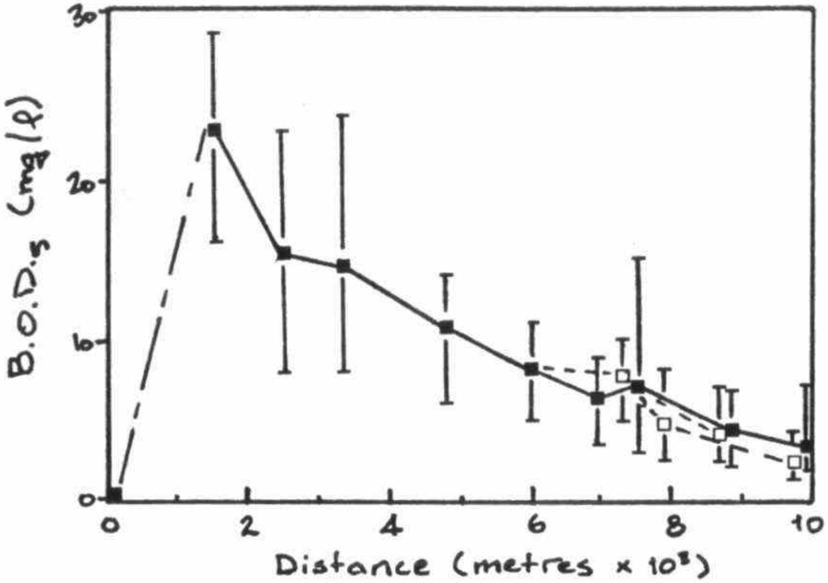
12
10
8
6
4
2
0
0
2
4
6
8
10
Distance (metres x 10³)


B.O.D.5 (mg/ℓ)
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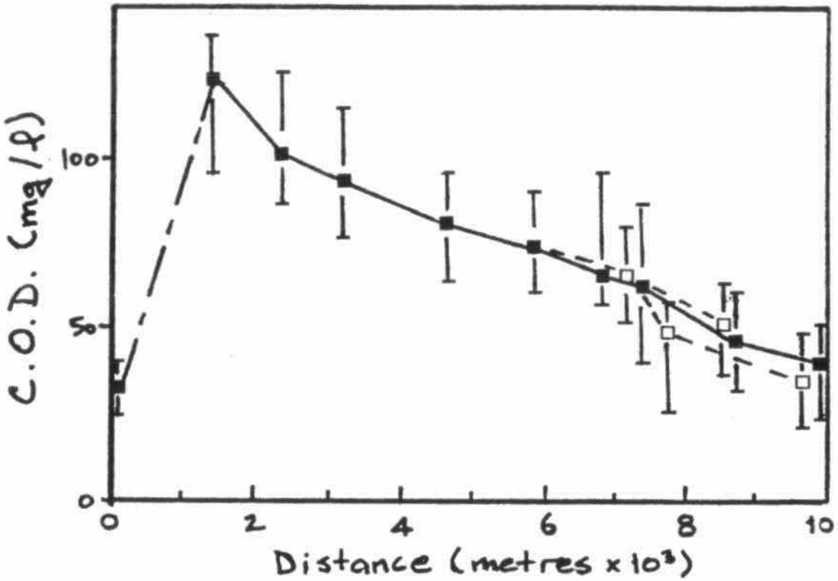
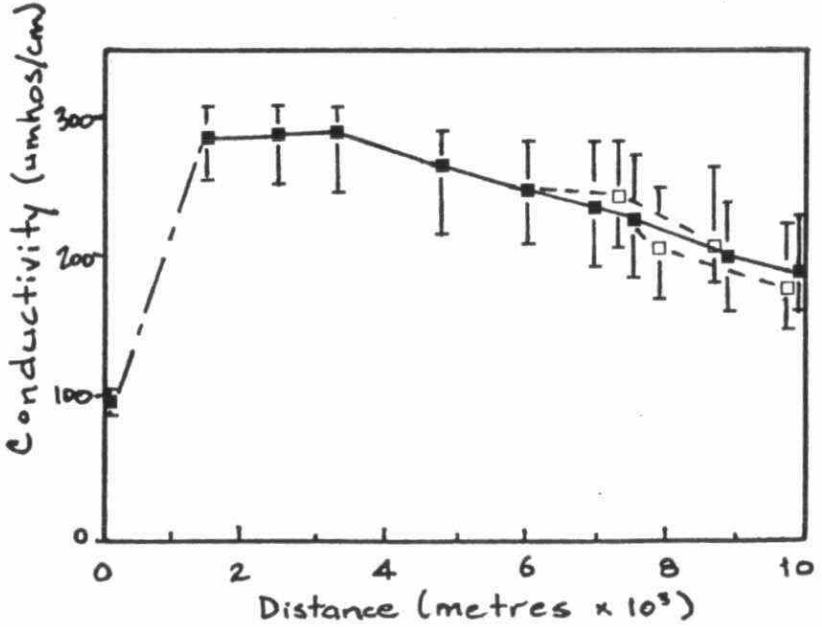
10
20
30
0
2
4
6
8
10
Distance (metres x 10³)


C.O.D. (mg/ℓ)
0
50
100
0
2
4
6
8
10
Distance (metres x 10³)


Conductivity (umhos/cm)
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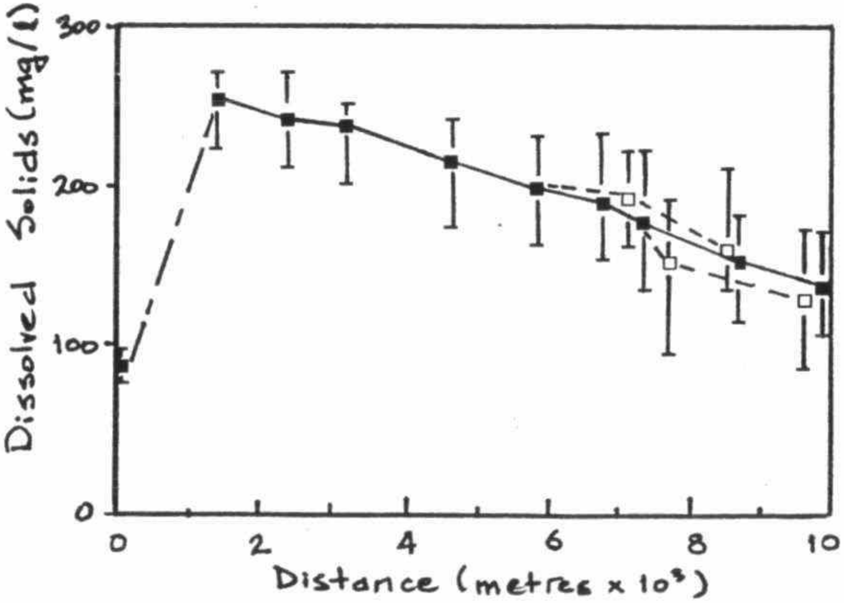
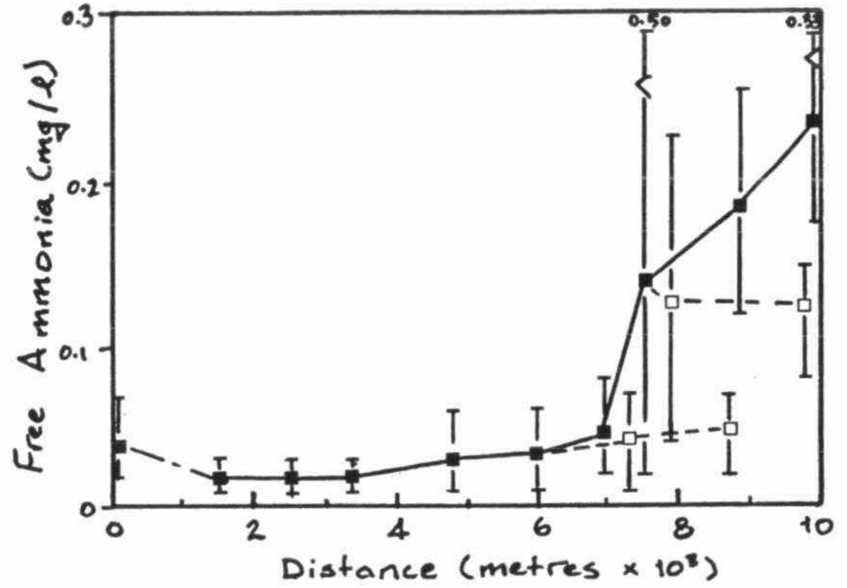
100
200
300
0
2
4
6
8
10
Distance (metres x 10³)


Dissolved Solids (mg/ℓ)
0
100
200
300
0
2
4
6
8
10
Distance (metres x 10³)



Free Ammonia (mg/ℓ)
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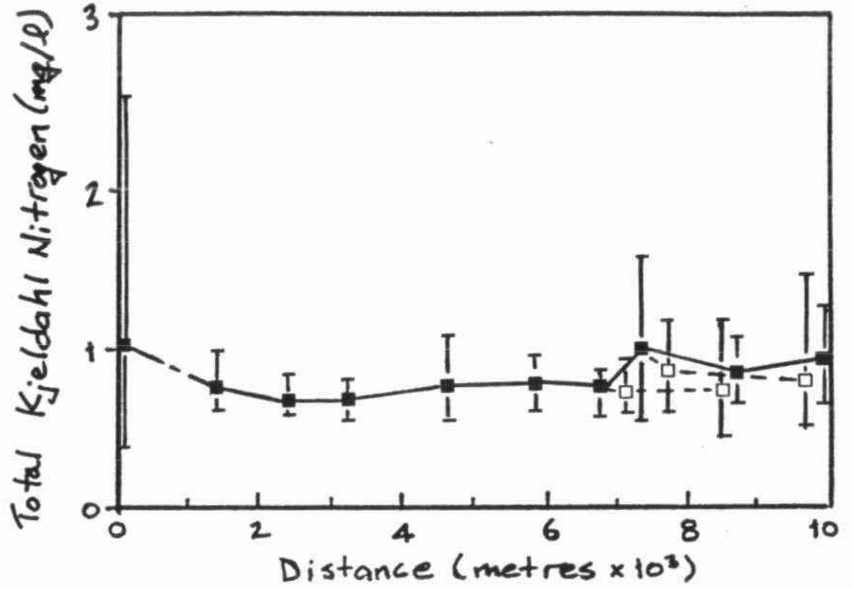
0.2
0.1
0
0.50
0.55
0
2
4
6
8
10
Distance (metres × 10³)



Total Kjeldahl Nitrogen (mg/ℓ)
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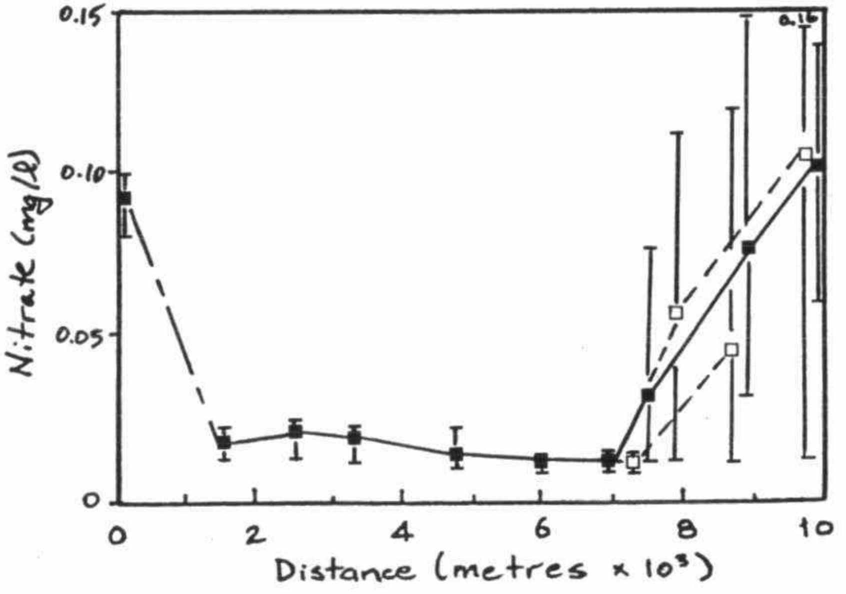
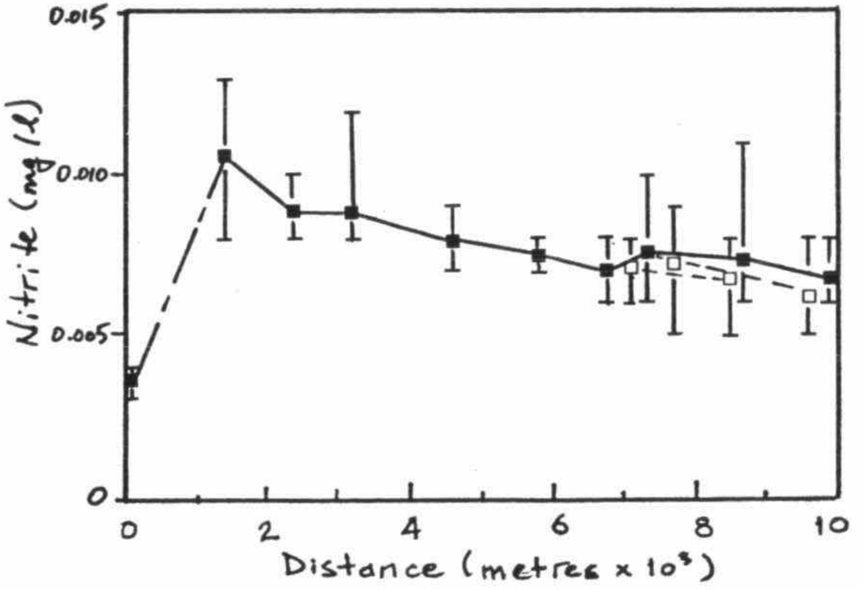
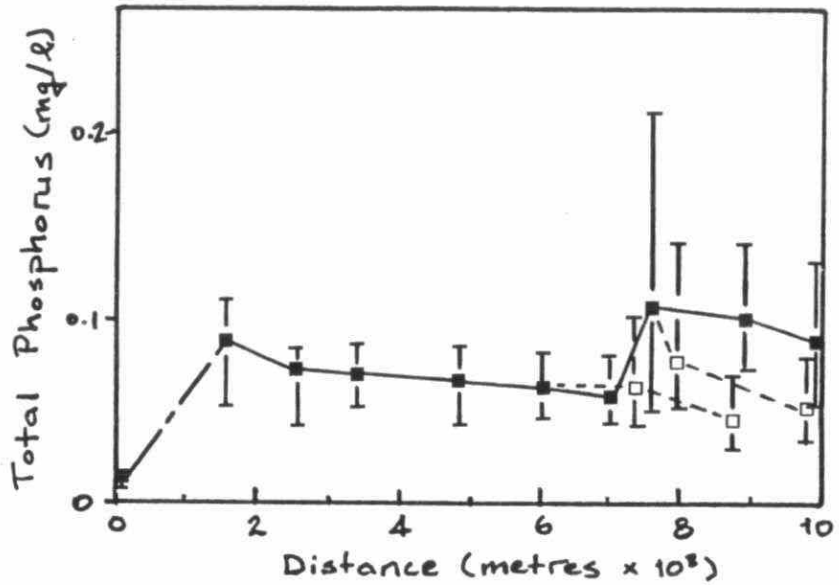
2
1
0
0
2
4
6
8
10
Distance (metres × 10³)

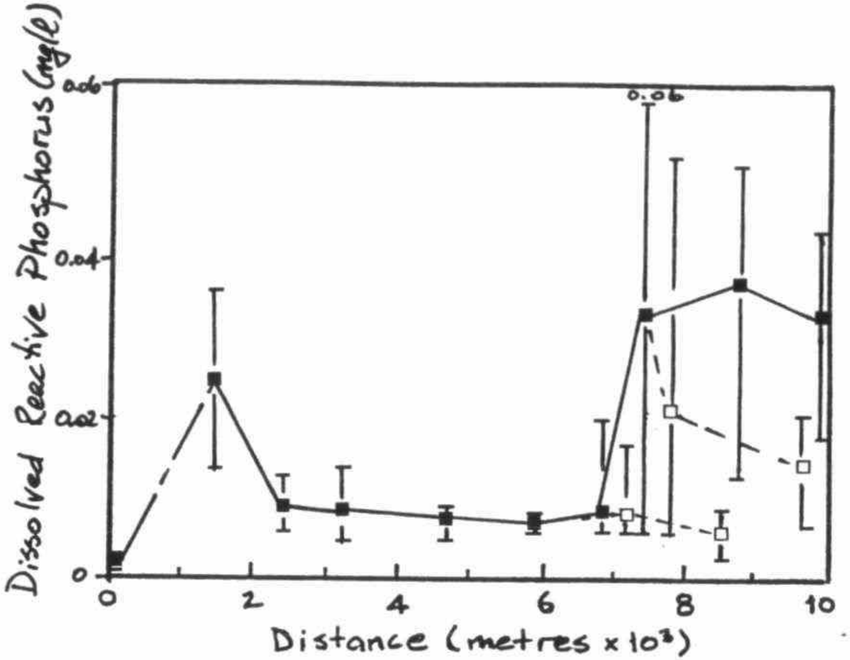


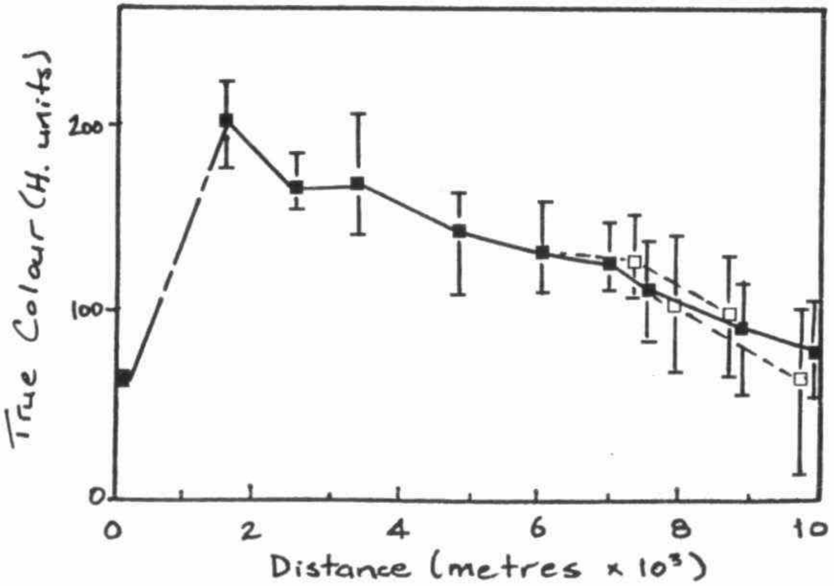
Nitrate (mg/ℓ)
0.15
0.10
0.05
0
0.16
0
2
4
6
8
10
Distance (metres × 10³)

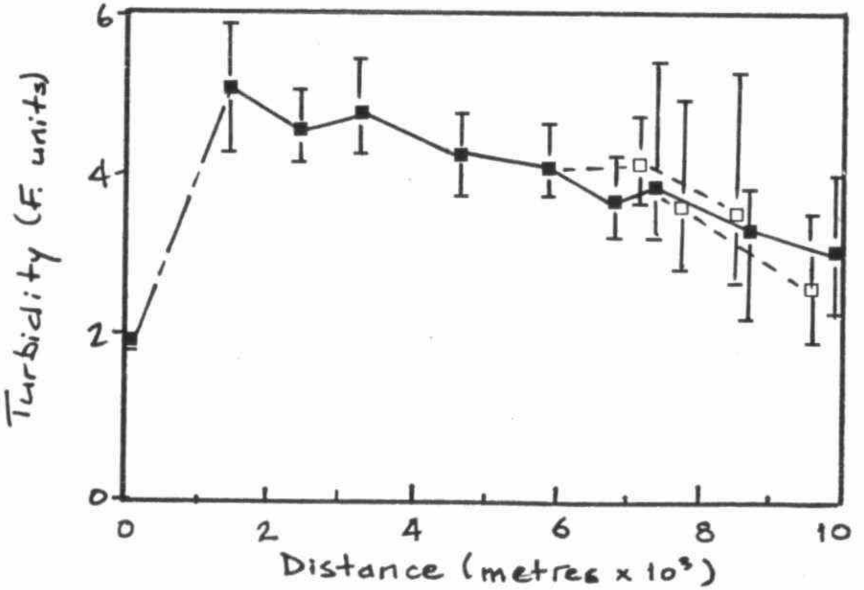


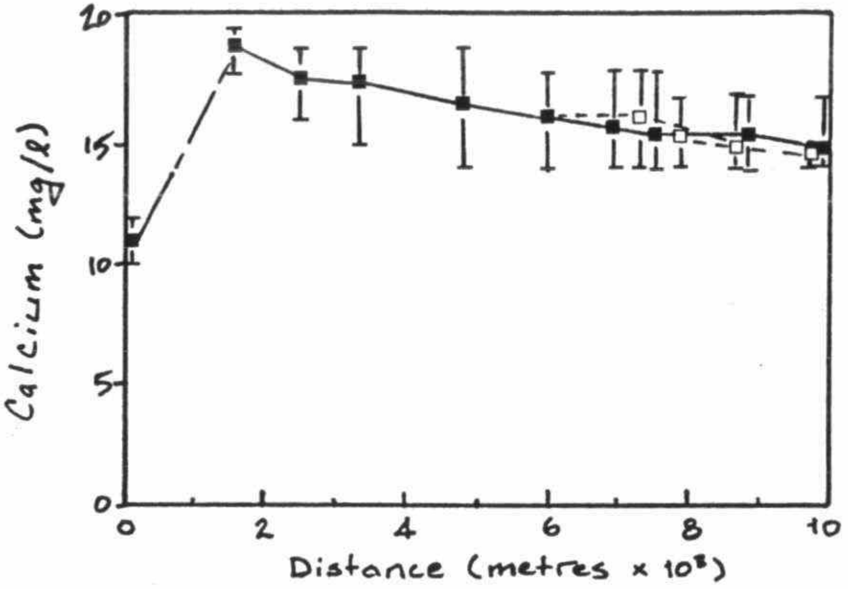
Nitrite (mg/ℓ)
0.015
0.010
0.005
0
0
2
4
6
8
10
Distance (metres × 10³)

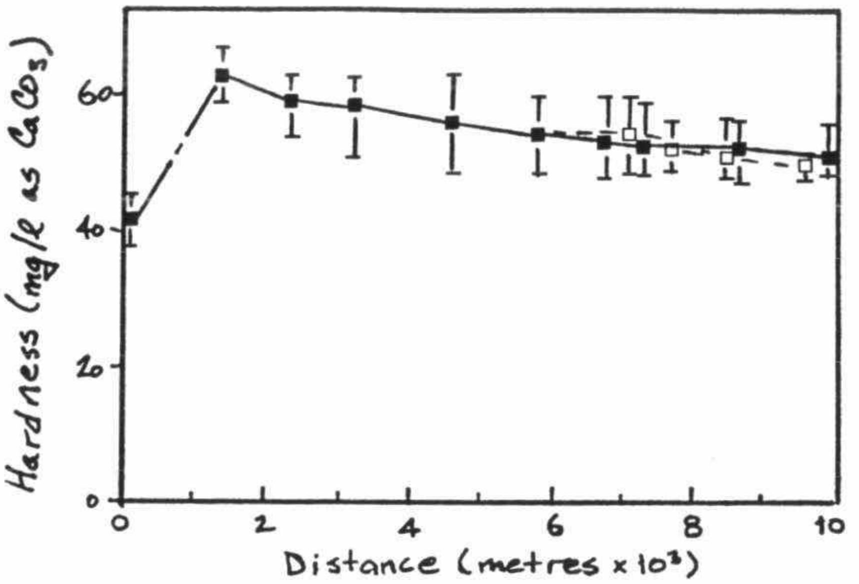

Total Phosphorus (mg/ℓ)
0.2
0.1
0
0
2
4
6
8
10
Distance (metres × 10³)

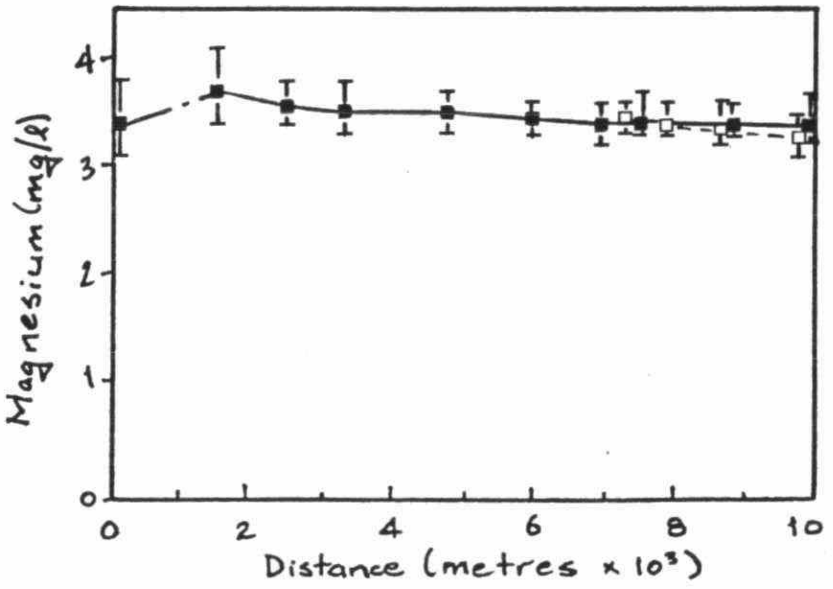

Dissolved Reactive Phosphorus (mg/ℓ)
0.06
0.04
0.02
0
0.06
0
2
4
6
8
10
Distance (metres × 10³)

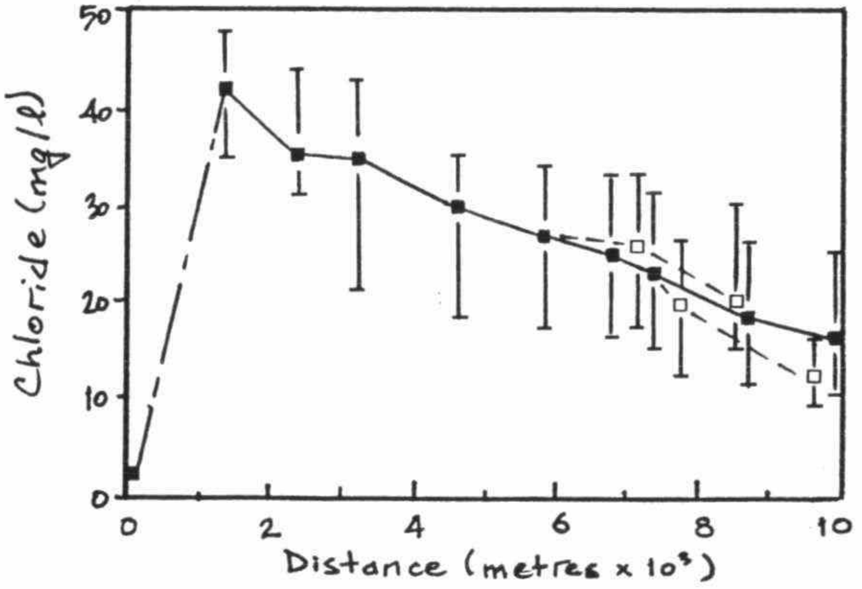

True Colour (H. units)
200
100
0
0
2
4
6
8
10
Distance (metres × 10³)

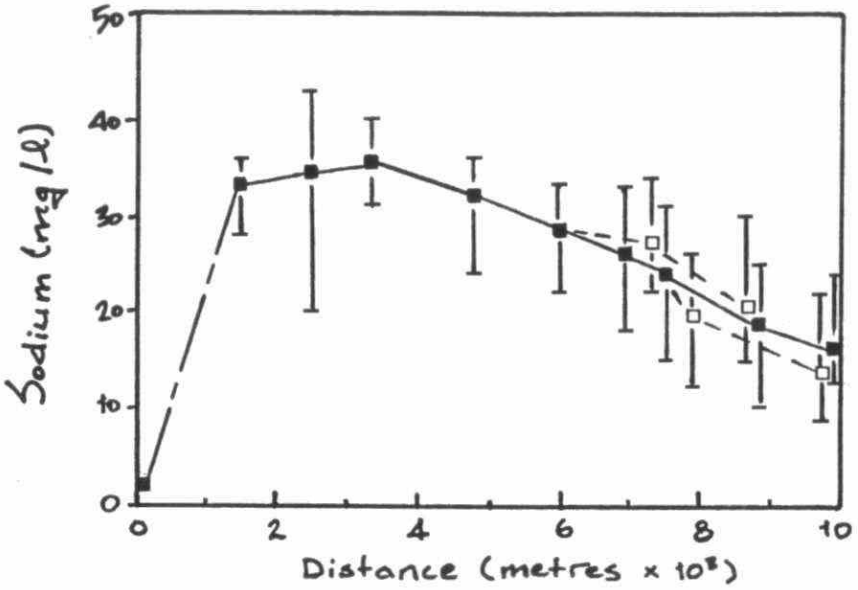

Turbidity (F. units)
6
4
2
0
0
2
4
6
8
10
Distance (metres × 10³)

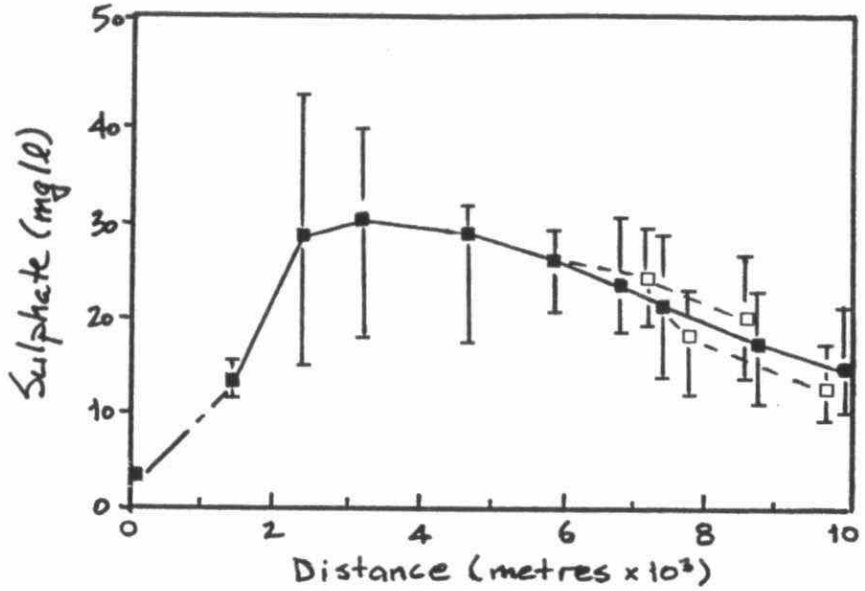

Calcium (mg/l)
0
5
10
15
20
0
2
4
6
8
10
Distance (metres x 10³)

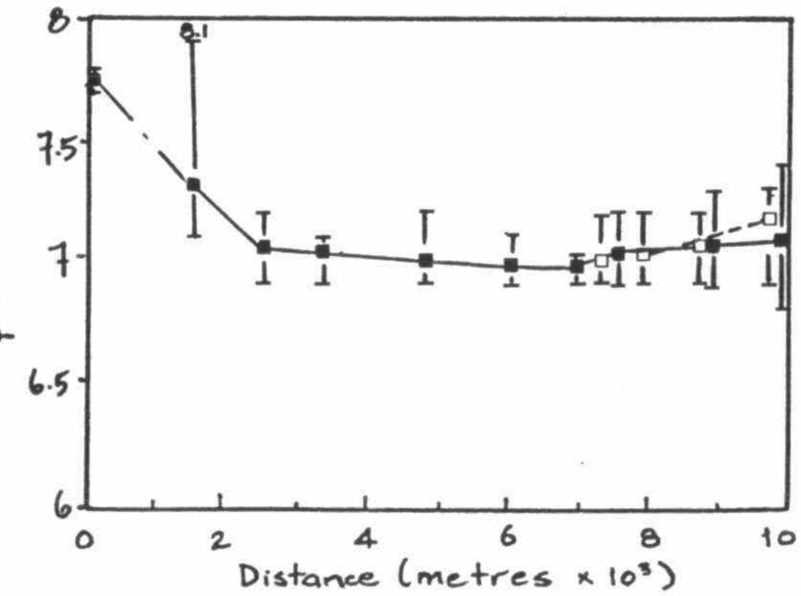

Hardness (mg/l as CaCO₃)
0
20
40
60
0
2
4
6
8
10
Distance (metres x 10³)

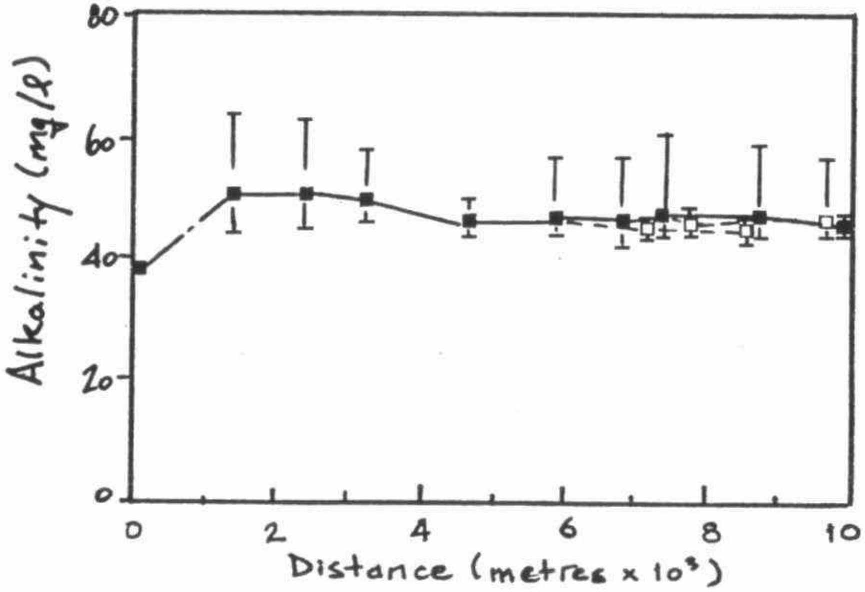

Magnesium (mg/l)
0
1
2
3
4
0
2
4
6
8
10
Distance (metres x 10³)


Chloride (mg/l)
0
10
20
30
40
50
0
2
4
6
8
10
Distance (metres x 10³)


Sodium (mg/l)
0
10
20
30
40
50
0
2
4
6
8
10
Distance (metres × 10³)


Sulphate (mg/l)
0
10
20
30
40
50
0
2
4
6
8
10
Distance (metres × 10³)


pH
6
6.5
7
7.5
8
8.1
0
2
4
6
8
10
Distance (metres × 10³)


Alkalinity (mg/l)
0
20
40
60
80
0
2
4
6
8
10
Distance (metres × 10³)

	BOD	TOTAL SOLIDS (MG/L)	DISSOLVED SOLIDS (MG/L)	SUSPENDED			COD	CONDUCTIVITY (UMHOS/CM)	TRUE COLOUR (H UNITS)	TURBIDITY	ALKALINITY	SODIUM (MG/L)
				DRIED	ASHED	LOSS						
STATION A												
- MAX	0.6	100	99	2	2	1	41	102	60	2.0	41	2.3
- MIN	0.2	77	75	1	1	0	25	84	67	1.8	36	1.6
- MEAN	0.41	88.1	86.2	1.9	1.2	0.7	32.9	91.8	62.6	1.88	38.3	1.87
- STD DEV	0.127	8.19	8.38	0.33	0.44	0.50	5.80	5.56	2.19	0.10	1.87	0.24
STATION BL												
- MAX	30.0	270	264	9	3	6	140	293	228	6.1	62	36.0
- MIN	16.0	200	194	5	1	2	90	223	153	4.4	45	27.0
- MEAN	21.33	241.1	234.9	6.4	2.4	4.0	108.3	266.7	188.3	4.96	49.7	30.33
- STD DEV	4.72	19.65	19.53	1.24	0.73	1.41	17.85	21.42	25.44	0.53	5.89	3.43
STATION BM												
- MAX	29.0	280	272	10	4	9	135	308	223	5.9	64	36.0
- MIN	16.0	230	224	5	1	3	96	254	177	4.3	44	28.0
- MEAN	23.11	260.0	254.0	6.9	2.1	4.8	123.4	285.1	202.0	5.12	50.6	33.11
- STD DEV	4.226	15.00	14.76	1.76	1.05	1.79	13.20	16.07	15.07	0.432	6.41	2.93
STATION BR												
- MAX	33.0	300	310	10	6	6	170	343	259	6.5	65	50.0
- MIN	16.0	220	214	5	1	2	96	245	172	4.2	45	25.8
- MEAN	26.33	270.0	262.7	7.3	2.9	4.4	127.9	299.8	213.1	5.29	51.7	36.44
- STD DEV	5.123	30.41	29.34	1.87	1.45	1.24	22.47	30.51	30.18	0.788	6.12	7.75
STATION C												
- MAX	23.0	280	272	8	3	6	125	309	185	5.1	63	43.0
- MIN	8.0	220	212	6	1	4	87	251	154	4.2	45	20.0
- MEAN	15.44	248.9	242.1	6.8	2.1	4.7	100.9	288.3	165.4	4.58	50.8	34.44
- STD DEV	4.19	17.64	17.74	0.83	0.60	0.71	11.67	19.29	10.08	0.32	6.82	6.82

FREE AMMONIA (MG/L)	TOTAL KJELDAHL (MG/L)	NITRITE (MG/L)	NITRATE (MG/L)	TOTAL PHOSPHORUS (MG/L)	DISSOLVED REACTIVE P (MG/L)	PH	CHLORIDE (MG/L)	SULPHATE (MG/L)	CALCIUM (MG/L)	MAGNESIUM (MG/L)	HARDNESS (as CaCO3)
0.07	2.60	0.004	0.100	0.014	0.003	7.8	2.3	3.90	12	3.8	45.6
0.02	0.40	0.003	0.080	0.008	0.001	7.7	1.5	3.20	10	3.1	37.7
0.039	1.043	0.0036	0.0924	0.0109	0.0019	7.74	1.89	3.584	11.1	3.40	41.7
0.016	0.68	0.0005	0.0078	0.0021	0.0008	0.053	0.28	0.22	0.928	0.24	3.2
0.03	1.00	0.013	0.020	0.100	0.021	8.1	45.0	19.50	20	4.1	65.6
0.01	0.55	0.007	0.010	0.062	0.004	7.0	32.0	10.60	17	3.3	56.8
0.021	0.767	0.0094	0.0166	0.0819	0.0151	7.27	37.33	14.222	18.6	3.63	61.3
0.006	0.17	0.0017	0.0040	0.0138	0.0055	0.33	4.44	2.91	1.13	0.24	2.99
0.03	1.00	0.013	0.020	0.110	0.036	8.2	48.0	15.20	20	4.1	66.8
0.01	0.63	0.008	0.010	0.052	0.014	7.1	35.0	11.70	18	3.4	58.9
0.018	0.763	0.0106	0.0160	0.0878	0.0244	7.31	41.78	13.156	19.1	3.69	62.9
0.007	0.11	0.0017	0.0037	0.0178	0.0091	0.36	4.35	1.17	0.93	0.196	2.756
0.02	1.10	0.015	0.020	0.120	0.040	8.1	56.0	18.40	22	4.0	69.3
0.01	0.69	0.008	0.010	0.052	0.009	7.0	30.0	12.10	18	3.5	61.4
0.017	0.789	0.0112	0.0172	0.0966	0.0273	7.29	44.67	13.989	19.7	3.70	64.3
0.0050	0.1248	0.0023	0.0032	0.0238	0.0130	0.33	8.56	2.00	1.22	0.173	2.798
0.03	0.85	0.010	0.022	0.084	0.013	7.2	44.0	43.30	19	3.8	62.7
0.01	0.60	0.008	0.010	0.042	0.006	6.9	31.0	15.00	16	3.4	53.9
0.019	0.692	0.0089	0.0189	0.0723	0.0090	7.06	35.00	28.511	17.8	3.54	59.0
0.0060	0.0803	0.0009	0.0036	0.0140	0.0023	0.10	3.87	8.45	1.20	0.15	3.38

	BOD	TOTAL SOLIDS (MG/L)	DISSOLVED SOLIDS (MG/L)	SUSPENDED			COD	CONDUCTIVITY (UMHOS/CM)	TRUE COLOUR (H UNITS)	TURBIDITY	ALKALINITY	SODIUM (MG/L)
				DRIED	ASHED	LOSS						
STATION D												
- MAX	24.0	260	252	9	4	6	115	307	206	5.5	58	40.0
- MIN	8.0	210	202	7	2	4	77	245	141	4.3	46	31.0
- MEAN	14.73	244.4	236.8	7.7	2.7	5.0	93.6	289.8	167.8	4.81	49.6	35.67
- STD DEV	4.74	15.90	15.81	0.71	0.87	0.71	12.46	18.54	17.51	0.49	3.75	2.74
STATION F												
- MAX	14.0	250	242	9	3	6	95	290	163	4.8	50	36.0
- MIN	6.0	180	174	6	1	3	64	215	109	3.8	44	24.0
- MEAN	10.69	222.2	214.9	7.3	2.2	5.1	81.6	264.9	141.2	4.29	46.6	32.00
- STD DEV	4.36	21.96	21.66	0.86	0.78	0.87	11.98	24.93	21.51	0.50	3.33	3.82
STATION G												
- MAX	11.0	240	232	8	4	5	90	283	158	4.7	57	33.0
- MIN	4.9	170	163	3	1	2	61	207	109	3.8	44	22.0
- MEAN	8.17	205.6	198.8	6.8	2.6	4.2	74.2	246.3	128.8	4.13	47.1	28.44
- STD DEV	1.87	21.86	21.27	1.56	0.88	1.09	10.72	24.41	13.61	0.31	3.95	3.81
STATION H												
- MAX	10.0	230	222	15	6	10	80	282	151	4.8	47	34.0
- MIN	4.8	170	163	7	2	4	52	205	106	3.7	44	22.0
- MEAN	7.67	202.2	193.1	9.1	4.0	5.1	65.8	241.6	126.0	4.22	45.4	27.33
- STD DEV	1.58	19.86	19.39	2.42	1.32	1.96	8.06	25.60	14.17	0.41	1.24	3.97
STATION I												
- MAX	7.0	220	212	12	8	7	64	263	129	5.4	47	30.0
- MIN	2.2	140	135	5	1	2	37	179	63	2.7	43	15.0
- MEAN	4.02	167.8	160.9	6.9	3.1	3.8	51.9	205.0	97.8	3.60	45.0	20.67
- STD DEV	1.36	24.38	23.45	2.26	2.03	1.39	8.65	27.57	19.44	0.84	1.12	4.90

FREE AMMONIA (MG/L)	TOTAL KJELDAHL (MG/L)	NITRITE (MG/L)	NITRATE (MG/L)	TOTAL PHOSPHORUS (MG/L)	DISSOLVED REACTIVE P (MG/L)	PH	CHLORIDE (MG/L)	SULPHATE (MG/L)	CALCIUM (MG/L)	MAGNESIUM (MG/L)	HARDNESS (as CaCO3)
0.03	0.82	0.012	0.020	0.085	0.014	7.1	43.0	39.80	19	3.8	62.3
0.01	0.57	0.008	0.009	0.051	0.005	6.9	21.0	17.80	15	3.3	51.0
0.019	0.693	0.0088	0.0168	0.0694	0.0086	7.04	34.56	30.189	17.6	3.50	58.2
0.006	0.088	0.0013	0.0042	0.0151	0.0028	0.07	6.29	5.95	1.42	0.15	3.75
0.06	1.10	0.009	0.020	0.084	0.009	7.2	35.0	31.70	19	3.7	62.7
0.01	0.58	0.007	0.007	0.042	0.005	6.9	18.0	17.50	14	3.3	48.5
0.029	0.782	0.0079	0.0116	0.0657	0.0074	7.00	29.78	28.533	16.7	3.48	55.9
0.014	0.130	0.0011	0.0052	0.0149	0.0022	0.10	6.15	5.19	1.53	0.15	4.16
0.06	0.97	0.008	0.010	0.080	0.008	7.1	34.0	29.10	18	3.6	59.8
0.01	0.63	0.007	0.006	0.045	0.006	6.9	17.0	20.80	14	3.3	48.5
0.033	0.789	0.0074	0.0087	0.0608	0.0073	6.98	26.56	25.944	16.1	3.42	54.3
0.02	0.11	0.0005	0.0015	0.0129	0.0007	0.07	5.15	2.61	1.36	0.12	3.83
0.07	0.95	0.008	0.010	0.100	0.017	7.2	33.0	29.50	18	3.6	59.8
0.01	0.62	0.006	0.006	0.041	0.006	6.9	17.0	19.20	14	3.3	48.5
0.042	0.738	0.0071	0.0090	0.0614	0.0084	7.00	25.44	24.133	16.1	3.46	54.4
0.02	0.13	0.0006	0.0014	0.0196	0.0034	0.09	5.20	3.49	1.36	0.12	3.78
0.07	1.20	0.008	0.120	0.068	0.009	7.2	30.0	26.50	17	3.6	56.4
0.02	0.47	0.005	0.010	0.028	0.003	6.9	15.0	13.80	14	3.2	48.1
0.048	0.754	0.0068	0.0438	0.0443	0.0061	7.07	19.78	20.244	14.9	3.37	51.0
0.019	0.29	0.0010	0.0358	0.0134	0.0020	0.11	5.19	4.12	1.17	0.12	3.11

	BOD	TOTAL SOLIDS (MG/L)	DISSOLVED SOLIDS (MG/L)	SUSPENDED			COD	CONDUCTIVITY (UMHOS/CM)	TRUE COLOUR (H UNITS)	TURBIDITY	ALKALINITY	SODIUM (MG/L)
				DRIED	ASHED	LOSS						
STATION J												
- MAX	8.8	240	233	8	4	6	96	282	147	4.3	57	33.0
- MIN	3.4	160	154	6	1	4	57	191	110	3.3	42	18.0
- MEAN	6.17	196.7	189.9	6.8	2.1	4.7	65.9	234.3	124.0	3.73	46.6	25.78
- STD DEV	1.62	27.39	27.43	0.83	0.93	0.71	11.95	30.21	10.84	0.28	4.22	4.79
STATION KL												
- MAX	13.0	230	220	10	3	9	87	267	135	5.4	52	31.0
- MIN	3.1	140	134	5	1	3	44	187	82	3.1	45	16.0
- MEAN	7.26	185.6	177.2	8.3	2.0	6.3	62.9	224.8	104.0	4.04	47.8	23.67
- STD DEV	3.32	31.27	29.73	2.12	0.87	2.60	15.00	27.93	16.35	0.69	2.64	5.05
STATION KM												
- MAX	15.0	230	223	15	3	13	87	272	136	5.5	61	31.0
- MIN	2.9	140	135	4	1	3	40	183	81	3.3	44	15.0
- MEAN	7.03	184.4	177.0	7.4	2.0	5.4	62.7	224.0	110.0	3.91	47.4	23.78
- STD DEV	4.07	32.06	29.80	3.28	0.50	3.13	17.01	30.96	16.37	0.76	5.22	5.52
STATION KR												
- MAX	7.3	230	222	9	4	6	69	263	133	4.3	59	30.0
- MIN	3.1	150	142	6	2	4	46	185	64	3.3	44	17.0
- MEAN	5.29	185.6	178.6	7.0	2.6	4.4	57.8	222.8	107.2	3.81	47.0	23.67
- STD DEV	1.39	26.98	26.44	1.12	0.73	0.73	8.33	28.58	20.27	0.34	4.66	4.80
STATION L												
- MAX	8.0	200	192	10	3	7	58	248	139	5.0	49	26.0
- MIN	2.4	105	95	3	1	2	26	167	65	2.9	44	12.0
- MEAN	4.64	158.3	152.0	6.3	2.0	4.3	49.2	204.7	101.8	3.68	46.1	19.78
- STD DEV	1.80	30.00	30.01	2.06	0.87	1.87	10.24	24.33	20.50	0.60	1.36	4.27

FREE AMMONIA (MG/L)	TOTAL KJELDAHL (MG/L)	NITRITE (MG/L)	NITRATE (MG/L)	TOTAL PHOSPHORUS (MG/L)	DISSOLVED REACTIVE P (MG/L)	PH	CHLORIDE (MG/L)	SULPHATE (MG/L)	CALCIUM (MG/L)	MAGNESIUM (MG/L)	HARDNESS (as CaCO3)
0.08	0.89	0.008	0.011	0.079	0.020	7.0	33.0	30.40	18	3.6	59.8
0.02	0.59	0.006	0.007	0.042	0.006	6.9	16.0	18.60	14	3.2	48.1
0.047	0.768	0.0070	0.0090	0.0573	0.0086	6.98	24.44	23.633	15.7	3.37	53.0
0.020	0.11	0.0009	0.0015	0.0132	0.0044	0.04	5.81	3.96	1.41	0.12	3.98
1.20	2.60	0.030	0.080	0.430	0.490	7.1	31.0	28.00	17	3.6	57.3
0.06	0.88	0.006	0.008	0.059	0.026	6.8	16.0	13.40	14	3.3	48.5
0.383	1.419	0.0099	0.0397	0.2121	0.1546	6.99	23.11	20.822	15.3	3.46	52.5
0.37	0.60	0.0076	0.0260	0.1245	0.1571	0.11	5.35	4.27	1.12	0.10	3.10
0.50	1.60	0.010	0.076	0.210	0.140	7.2	31.0	28.60	18	3.7	58.9
0.02	0.57	0.006	0.010	0.048	0.006	6.9	15.0	14.00	14	3.3	48.5
0.141	1.017	0.0076	0.0293	0.1060	0.0333	7.02	22.67	21.278	15.4	3.39	52.5
0.146	0.359	0.0011	0.0231	0.0607	0.0423	0.11	5.45	4.48	1.33	0.13	3.54
0.19	1.30	0.009	0.055	0.120	0.044	7.1	30.0	28.00	17	3.5	56.4
0.03	0.59	0.006	0.010	0.043	0.006	6.9	16.0	15.60	14	3.3	48.5
0.084	0.801	0.0072	0.0219	0.0660	0.0141	7.00	22.67	21.422	15.4	3.34	52.3
0.052	0.221	0.0010	0.0171	0.0222	0.0125	0.09	4.90	4.02	1.13	0.07	3.03
0.23	1.20	0.009	0.112	0.140	0.053	7.2	26.0	22.90	17	3.6	56.4
0.04	0.63	0.005	0.010	0.051	0.006	6.9	12.0	11.90	14	3.3	48.9
0.128	0.872	0.0072	0.0560	0.0757	0.0213	7.02	19.44	18.311	15.3	3.39	52.2
0.068	0.183	0.0012	0.0282	0.0288	0.0172	0.10	4.67	3.65	1.12	0.09	2.92

	BOD	TOTAL SOLIDS (MG/L)	DISSOLVED SOLIDS (MG/L)	SUSPENDED DRIED	SUSPENDED ASHED	SUSPENDED LOSS	COD	CONDUCTIVITY (UMHOS/CM)	TRUE COLOUR (H UNITS)	TURBIDITY	ALKALINITY	SODIUM (MG/L)
STATION M												
- MAX	4.2	180	173	7	3	6	49	221	100	3.6	57	22.0
- MIN	1.2	89	86	3	1	1	22	145	10	2.0	44	8.6
- MEAN	2.21	133.2	129.2	4.0	1.7	2.3	35.0	174.3	62.3	2.68	46.4	13.68
- STD DEV	0.94	29.34	28.11	1.41	0.71	1.50	10.04	25.21	26.60	0.50	4.00	4.41
STATION O												
- MAX	6.8	190	182	9	3	7	61	239	114	3.9	59	25.0
- MIN	2.0	120	116	4	1	2	32	158	53	2.3	44	10.0
- MEAN	4.18	157.7	152.3	5.7	2.0	3.7	46.6	199.3	89.7	3.41	47.4	18.67
- STD DEV	1.74	24.89	23.25	1.80	0.87	1.80	10.24	27.31	18.76	0.48	4.45	5.12
STATION PL												
- MAX	7.2	190	181	9	3	8	53	230	104	4.3	48	24.0
- MIN	1.1	95	92	3	1	2	22	128	33	1.7	45	6.6
- MEAN	3.32	141.7	136.8	4.9	1.6	3.3	40.3	183.8	69.1	3.02	46.3	16.51
- STD DEV	2.01	30.82	28.89	2.20	0.73	2.00	11.36	32.83	25.71	0.80	1.22	5.27
STATION PM												
- MAX	7.2	180	172	8	3	7	52	228	105	4.1	47	24.0
- MIN	1.6	110	107	3	1	1	24	162	52	2.4	45	10.0
- MEAN	3.23	142.2	137.4	4.8	1.7	3.1	40.2	186.8	75.3	3.16	46.1	16.22
- STD DEV	1.73	22.24	20.71	1.72	0.71	1.69	8.30	23.30	16.15	0.54	0.93	4.32
STATION PR												
- MAX	5.4	180	175	7	2	5	46	220	98	3.7	48	22.0
- MIN	1.6	110	107	3	1	1	26	156	52	2.4	44	11.0
- MEAN	2.80	138.9	134.6	4.3	1.7	2.7	37.9	182.9	74.0	3.00	46.2	15.33
- STD DEV	1.15	21.47	20.54	1.22	0.50	1.22	6.74	20.42	13.29	0.37	1.39	3.54

FREE AMMONIA (MG/L)	TOTAL KJELDAHL (MG/L)	NITRITE (MG/L)	NITRATE (MG/L)	TOTAL PHOSPHORUS (MG/L)	DISSOLVED REACTIVE P (MG/L)	PH	CHLORIDE (MG/L)	SULPHATE (MG/L)	CALCIUM (MG/L)	MAGNESIUM (MG/L)	HARDNESS (as CaCO3)
0.15	1.50	0.008	0.160	0.078	0.021	7.3	16.0	17.4	15	3.5	51.8
0.08	0.55	0.005	0.010	0.033	0.007	6.9	8.9	9.3	14	3.1	47.7
0.125	0.816	0.0061	0.1050	0.0511	0.0146	7.18	12.09	12.76	14.6	3.30	50.1
0.028	0.305	0.0011	0.0472	0.0138	0.0053	0.15	2.40	2.89	0.52	0.120	1.486
0.26	1.10	0.011	0.150	0.140	0.052	7.3	26.0	22.8	17	3.6	56.4
0.12	0.69	0.006	0.030	0.072	0.013	6.9	11.0	11.1	14	3.3	48.5
0.187	0.877	0.0073	0.0763	0.0978	0.0374	7.06	18.11	17.28	15.3	3.37	52.1
0.044	0.139	0.0016	0.0358	0.0213	0.0123	0.12	5.23	3.88	1.12	0.10	3.04
0.30	1.40	0.010	0.180	0.140	0.054	7.5	26.0	21.0	16	3.6	53.9
0.11	0.64	0.004	0.043	0.037	0.013	6.9	6.9	7.5	14	3.2	48.1
0.237	0.986	0.0072	0.1074	0.0871	0.0316	7.13	16.01	14.28	14.9	3.38	51.1
0.058	0.228	0.0020	0.0471	0.0330	0.0132	0.20	6.07	5.08	0.78	0.12	2.24
0.33	1.30	0.008	0.140	0.130	0.044	7.4	25.0	21.3	17	3.7	56.0
0.18	0.69	0.006	0.059	0.055	0.018	6.8	10.0	10.2	14	3.2	48.1
0.241	0.958	0.0068	0.1013	0.0876	0.0331	7.09	16.00	15.02	14.9	3.38	51.1
0.058	0.205	0.0007	0.0264	0.0235	0.0085	0.18	4.72	3.61	1.05	0.15	2.83
0.35	1.80	0.008	0.150	0.110	0.046	7.4	24.0	20.3	16	3.7	54.3
0.18	0.82	0.006	0.076	0.060	0.025	6.8	10.0	10.2	14	3.2	48.1
0.241	1.093	0.0066	0.1042	0.0810	0.0321	7.12	15.33	14.44	14.9	3.39	51.1
0.067	0.309	0.0007	0.0290	0.0165	0.0069	0.19	4.21	3.33	0.78	0.15	2.16

	BOD	TOTAL SOLIDS (MG/L)	DISSOLVED SOLIDS (MG/L)	SUSPENDED			COD	CONDUCTIVITY (UMHOS/CM)	TRUE COLOUR (H UNITS)	TURBIDITY	ALKALINITY	SODIUM (MG/L)
				DRIED	ASHED	LOSS						
GLA												
- MAX	335	2400	2330	100	50	70	1290	2495	1970	32	298	430
- MIN	250	1830	1760	45	10	35	955	1820	34	19	150	320
- MEAN	283	2066	1994	72	23	49	1088	2147	1555	25	199	371
- STD DEV	25.7	215.2	217.0	18.2	11.5	10.5	113.4	251.4	595.1	3.9	46.6	37.9
GLB												
- MAX	1.8	1200	1197	6	4	2	41	1730	42	3.4	41	350
- MIN	0.8	680	679	1	1	0	16	980	28	2.1	27	190
- MEAN	1.3	958	955	2.4	1.7	0.8	29	1393	33	2.6	32	289
- STD DEV	0.39	139.98	139.56	1.51	1.00	0.67	8.12	210.20	4.09	0.43	4.61	49.36
RC												
- MAX	33	1540	1390	170	3	187	1450	3240		540	1584	310
- MIN	26	1500	1340	140	1	148	1150	2520		450	1252	290
- MEAN	29	1516	1359	157	1.3	161	1250	2961		496	1440	297
- STD DEV	2.6	17.4	16.9	10.0	0.7	12.6	91.2	265.6		36.1	95.0	8.7
IGP												
- MAX	11500	15360	10470	5470	380	5090	18030	5400	219	1300	1484	830
- MIN	155	1570	1420	150	6	144	595	2110		63	0	360
- MEAN	2605	6277	4108	2169	203	1966	5859	4133		540	918	657
- STD DEV	4151	4951	3198	1833	135	1752	6398	1208		411	570	163
STP												
- MAX	76	500	445	55	25	30	160	670	301	48	162	48
- MIN	40	420	370	20	10	10	105	580	136	20	119	35
- MEAN	55	460	421	39	17	22	136	638	204	34	131	42
- STD DEV	12.6	27.8	25.2	14.1	6.2	8.3	18.6	29.5	63.9	10.0	13.7	4.0

FREE AMMONIA (MG/L)	TOTAL KJELDAHL (MG/L)	NITRITE (MG/L)	NITRATE (MG/L)	TOTAL PHOSPHORUS (MG/L)	DISSOLVED REACTIVE P (MG/L)	PH	CHLORIDE (MG/L)	SULPHATE (MG/L)	CALCIUM (MG/L)	MAGNESIUM (MG/L)	HARDNESS (as CaCO3)
	2.8			1.1		8.1	613	134	110	7.3	304.9
	0.27			0.12		6.5	380	70	63	6	185.0
	2.21			0.90		6.9	494	100	94	6.8	262.7
	0.77			0.30		0.51	79.73	19.13	16.19	0.43	41.37
0.040	0.79	0.0020	0.19	0.039	0.025	7.3	72	679	16	3.9	55.6
0.020	0.42	0.0010	0.14	0.015	0.005	6.8	12	401	11	3.2	40.6
0.030	0.61	0.0016	0.16	0.024	0.012	7.1	28	534	12	3.6	44.8
0.009	0.15	0.0005	0.01	0.0089	0.007	0.181	22.54	80.7	1.62	0.23	4.68
270	350	0.50	5.5	3.3	3	8.4	24	338	10	2.8	35.8
175	270	0.30	0.25	0.9	0.026	8.1	14	39.3	8.6	2.1	32.2
235	316	0.43	2.6	2.1	1.6	8.3	17	135.1	9.5	2.5	34.0
31.1	24.5	0.09	2.3	0.82	0.90	0.14	3.9	95.0	0.43	0.21	1.16
200	530	5	45	160	100	8.5	1800	33.6	17	65	308.9
20	85	0.058	0.001	51	33	4	338	17.6	7.9	19	97.6
133	374	1.1	10.1	118	81	7.1	1016	25.5	13.7	46	224.5
75	133	1.49	13.6	31	20	1.73	479.5	4.03	2.94	13.4	61.38
15	37	0.081	0.5	2.2	0.98	7.2	113	31.8	38	15	156.5
9	15	0.01	0.007	0.83	0.05	6.8	87	23.2	32	12	129.2
12	20	0.048	0.196	1.35	0.48	7.0	98	28.6	37	13.2	145.9
2.3	6.7	0.023	0.20	0.46	0.27	0.14	9.06	2.36	1.94	1.09	8.57

APPENDIX D:

DOMOD3 MODELLING

DOMOD3, the MOE steady state D.O. model, is described in detail in the Stream Water Quality Assessment Procedures Manual (MOE, 1980). The description here will focus on the application of the model to the lower Kaministiquia River. The study area was divided into reaches based on the stream sampling stations as shown in figure D.1. Parameters affecting the D.O. regime are considered to be constant within a reach. Parameter values can be varied from reach to reach to reflect changing conditions. Table D.1 presents a summary of the final parameter values used in the modelling exercise.

Streamflow in reaches 1 and 2 were estimated by subtracting the effluent flows of the two GLFP outfalls, from the surveyed streamflow of 20 m^3/s. This is based on the fact the GLFP withdraws process water from the Kaministiquia River. Reach streamflows are required to determine the dissolved oxygen deficit and ultimate B.O.D. loads at the head of a reach receiving waste inputs. Streamflow in the Kaministiquia River below Station G and in the Mission and McKellar Rivers was estimated based on the percentage split between the three rivers as reported in the Thunder Bay Regional Water Quality Survey (MOE, 1972).

Times-of-Travel were determined as described in section 2.3 of the main report. Reach temperatures are the means of the survey data. Temperature is used to adjust rate coefficients as the temperature deviates from 20°C.

The ultimate carbonaceous and nitrogenous BOD at the head of reach $_1$ were estimated from the survey data.

Reach 1 deoxygenation rate coefficients were set at values expected in unpolluted waters. The carbonaceous BOD deoxygenation rate coefficient for reaches 2 through 16 was determined from a long-term B.O.D. test of GLFP effluent using a nitrogen inhibitor. This rate

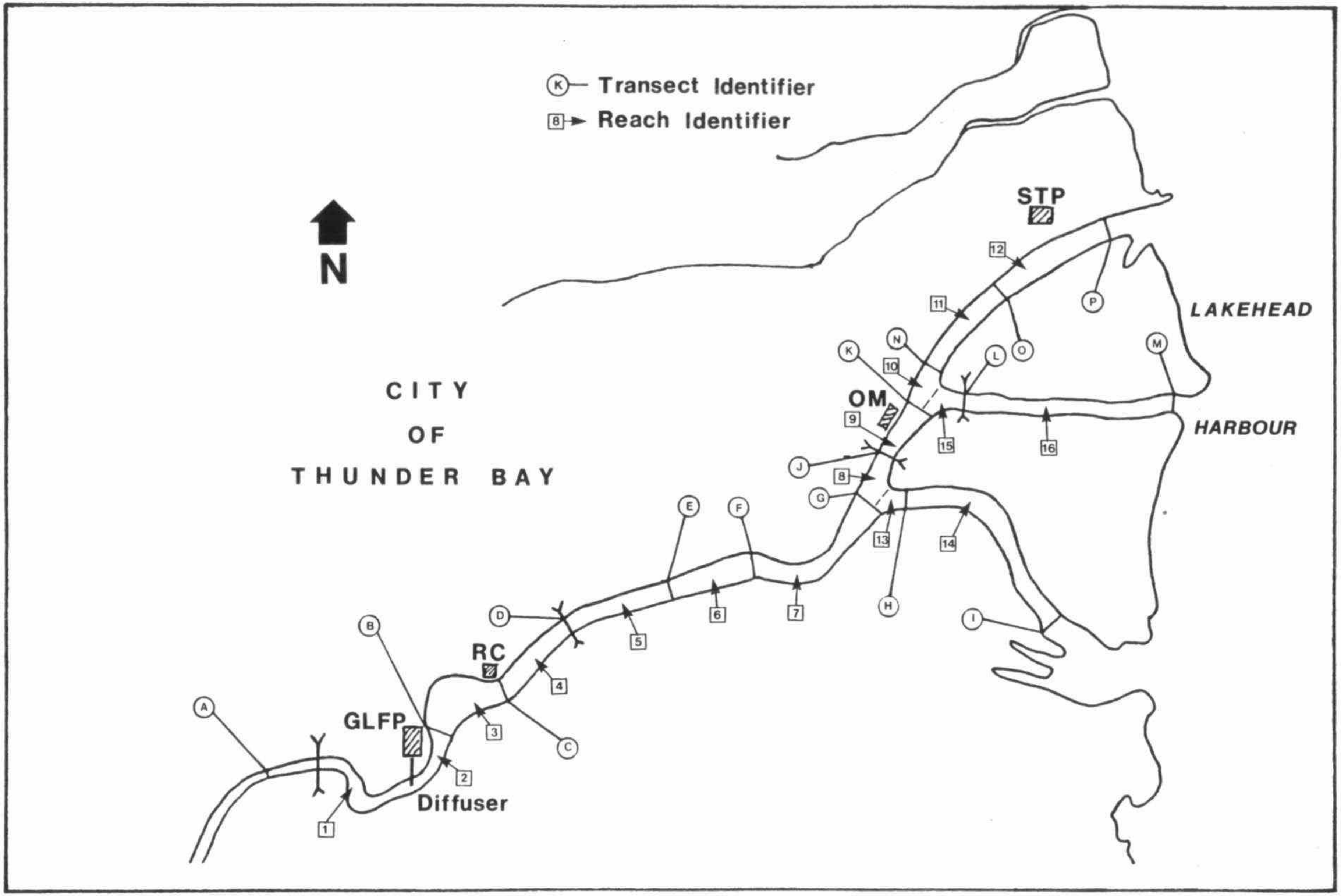


FIGURE D.1: Study Area Reach Designations.

TABLE D.1: DOMOD[3] PARAMETER VALUES

Reach	Streamflow (m^3/s)	Time-of-Travel (days)	Temperature (°C)	Ultimate CBOD (mg/l)	Ultimate NBOD (mg/l)	K[1]d	K[2]a	K[3]r	K[4]n	Sediment Oxygen Demand (mg/l per day)
1	17.05	0.272	20.0	0.46	4.07	0.20	0.103	0.20	0.02	1.0
2	18.96	0.097	21.4			0.343	0.088	2.0	1.0	
3	20.00	0.259	21.3				0.074	1.0	0.35	
4	20.004	0.119	21.0				0.095	1.0	0.30	
5	20.004	0.118	20.7				0.128	1.5	0.20	
6	20.004	0.072	20.4				0.15	1.5	0.25	
7	20.004	0.143	20.1				0.20	1.5	0.30	
8	11.602	0.112	19.5				0.20	1.5	0.25	
9	11.602	0.081	18.8				0.40	2.0	0.10	
10	8.006	0.066	18.3				0.60	2.0	0.10	
11	8.006	0.142	18.0				0.60	2.0	0.10	
12	8.006	0.184	17.6				0.60	1.5	0.10	
13	8.402	0.213	19.9				0.40	2.0	0.10	
14	8.402	0.230	19.3				0.40	2.0	0.10	
15	3.597	0.064	18.4				0.80	2.0	0.10	
16	3.597	0.292	18.0				0.80	2.0	0.10	

[1] Carbonaceous BOD removal coefficient solely due to deoxygenation.

[2] Reaeration Coefficient.

[3] Carbonaceous BOD removal coefficient.

[4] Nitrogenous BOD removal coefficient.

was applied to all reaches as the GLFP effluent dominates the study area. The reach reaeration coefficients were derived from empirical relationships taking into account molecular diffusion, stream velocity and mean stream depth. The overall carbonaceous and nitrogenous removal coefficients for reaches 2 to 16 were set to values expected for slow moving rivers and then adjusted to fit the observed instream decay of carbonaceous and nitrogenous wastes.

Sediment oxygen demand (S.O.D.) was determined from in-situ measurements. S.O.D. was only considered for reach 2 due to the lack of deposits in reach 1 and the underlying lake water in reaches 3 to 16.

Table D.2 presents the effluent data input to the model. Ultimate carbonaceous BOD was determined from long-term BOD tests. Ultimate nitrogenous BOD was determine using stoichiometric relationships.

TABLE D.2: EFFLUENT CHARACTERISTICS

Discharger	Ultimate CBOD (mg/l)	Ultimate NBOD (mg/l)	Average Flow Rate (m^3/s)
Great Lakes Forest Products			
- Diffuser	345.6	11.3	1.91
- Clean Water Outfall	1.8	2.8	1.04
Reichhold Chemical	41.2	1444.0	0.004
Ogilvie Mills Limited	670.2	1846.0	0.008
Thunder Bay Sewage Treatment Plant	77.0	92.8	1.11

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